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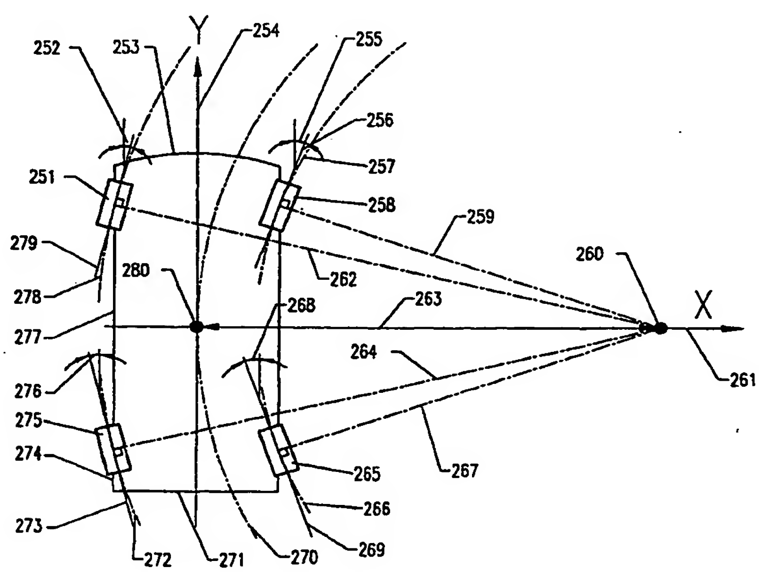

(57) Abstract

A method for controlling a vehicle of the type having a plurality of ground wheels which are individually steerable and driven such that each said wheel is tangential to a circle the center of which is common for all said wheels.

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A MODULAR WHEEL AND/OR CONVENTIONAL WHEEL ASSEMBLY AND CONTROL SYSTEM

FIELD OF THE INVENTION

This invention relates to a software/firmware based computer control system running on computers which may uniquely specify the angle of steer and speed of each of the wheels on the vehicle, the modular and other wheel assemblies, in addition to various other hardware items which may allow the implementation of a complete system in a vehicle.

BACKGROUND ART

Electronically driven ground wheels are know, and with improvements in fuel cell, solar cell and battery technology and also that the costs of these item generally falling, electric vehicles are becoming more common.

To date, electric vehicles consist of a vehicle body or chassis, a number of ground wheels (usually four), electric motors to drive at least some of the ground wheels, and batteries to power the vehicle.

It is known to have the front or rear wheels of a vehicle driven by electric motors. In one known version, a single electric motor drives a conventional propeller shaft through a differential to power the rear wheels. In another known version, electric motors are positioned adjacent each rear wheel and drive the wheels through suitable mechanical couplings.

Attempts have been made to improve the vehicle wheel grip on the road by using a computer-controlled system that varies the speed of rotation of each wheel.

For instance, European patent application 576947 discloses a driving system for a two or four wheel drive electric motor vehicle. Each driving wheel is coupled to its own motor that is a polyphase asynchronous motor. The motor of each driving wheel is connected to a central electric supply source consisting of batteries mounted on the vehicle chassis. The central electric supply source produces a polyphase current having a voltage and a frequency, which are variable by pulse width modulation under the control of an electronic regulating device. This device receives inputs on the one hand, set-value traction signals and set-value breaking signals on the other hand. A signal representative of the polyphase supply current and a set of frequency signals each of which comes from a respective sensor and represents the instantaneous speed of the drive motor and of the wheel associated with the drive motor. The device processes the input signals to deliver to a central supply to control signals which define respectively the frequency and the amplitude and thus the effective voltage of the common supply of the motors.

When a vehicle turns a corner, one of the wheels rotates faster than the other of the wheels and thus one of the frequency signals is selected by a processing unit as a reference signal to be used for regulating by a control unit whereas the other signal remains unused. The highest frequency signal is

selected so that regulation for all the drive motors (and therefore rotation of the wheels) is effected by considering only the fastest rotating motor and wheel.

This arrangement provides a simple, reliable electric braking mode and also minimise slipping of the wheels by detecting the differential rotation speed and sending appropriate signals to the drive motors to speed up or slow down.

Australian patent application 10185/97 improves on the European patent application by providing further sensors and feedback devices to prevent the driving wheels racing in the event of skidding in drive mode.

International patent application WO 98/19875 describes a modular wheel assembly and means to control the r.p.m and steering of the wheels.

A disadvantage with known devices is in being able to accurately control the r.p.m and steering of the wheels. If this could be achieved, the vehicle could adopt a cruise control and a crab control mode without undue stresses and strains being placed on the vehicle components.

OBJECT OF THE INVENTION

It is an object of the invention to provide a modular wheel or track assembly (vector wheel module) or other wheel assembly, and a software control system and various methods and components including operator controls which can overcome at least some of the above mentioned disadvantages.

It is a further object of the invention to provide a method of steering a vehicle that may allow for the control of the angle of steer of some or all of the vehicles wheel is by software running on a computer located in the vehicle and referred to here as the Motion Control Software.

It is a further object of the invention to provide a method of controlling typically the direction and speed of typically all the wheels by software running in a computer located on the vehicle, and referred to here as Motion Control Software.

It is a further object of the invention to have the method used by the Motion Control Software controlling the speed and direction of all the vector wheel modules and or other wheel assemblies on the vehicle in such a way as to achieve improved traction, roadholding and braking particularly when the vehicle is manoeuvring in rugged terrain or confined spaces and in particular where significant angles of steer are required.

It is a further object of the invention to provide a number of different operating modes.

It is a further object of the invention to make it possible to operate within the modes, and to change between these operating modes in a systematic manner.

It is a further object of the invention to provide an optional steering override mechanism which, should a software controlled steering system fail, will allow a mechanical linkage to take over the steering of one or more of the wheels.

It is a further object of the invention that the steering override mechanism does not significantly reduce the advantages of the software controlled steering system.

It is a further object of the invention that the operator's controls, and in particular steering wheel, provide tactile feedback to the operator. This will enable the operator to sense the force being exerted by the vehicles wheels on the ground as it turns a corner etc.

It is a further object of the invention to provide operator controls that allow the vehicle to be driven by people that are licensed or qualified to drive a conventional vehicle of a similar class (i.e. car, truck, tractor, mining equipment etc).

It is a further object of the invention to provide a vehicle having at least one of the said vector wheel modules, or two TWS or one TWO.

In one form, the invention resides in a method for controlling a vehicle of the type having a plurality of ground wheels which are individually steerable and driven such that each said wheel is tangential to a circle the centre of which is common for all said wheels. This manner of operation being referred to here as Cruise Mode.

Suitably, the RPM of the wheels is controlled as follows:

$$RPM_{\pm\Phi dn} = \frac{FR \times K_{RPM} \times (Am - FBRKm) \times Rw_{\pm\Phi dn}}{Rr}$$

Where:	$RPM_{\pm\Phi dn}$	=	The RPM command to wheel n, when in cruise mode $_{\pm\Phi dn}$ and using vector datum point d.
	Rr	=	Rc if Rc > = Ravd
	Rr	=	Rav if Ravd >= Rc
	Rc	=	Ssw x Kr cotan Kσ σsw
	where Rc	=	The radius 6f the circle.
	FR	=	1 when the vehicle is travelling forward
		=	- 1 when the vehicle is travelling in reverse
	K_{RPM}	=	The vehicles RPM constant.
		=	The RPM of the vehicles wheels when it is travelling in a straight line (i.e., Rc = infinity) at top speed (i.e., Acc = 1).
	K_{RPM}	=	$\frac{1\,000\ Vmax}{120\pi\ Rewr} = \frac{2.653\ Vmax}{Rewr}$
	Vmax	=	Vehicles maximum speed in km/hr.
	Rewr	=	The effective wheel radius in meters.
	Am	=	Am if Am >= K_{idle}
	Am	=	K_{idle} if K_{idle} > Am
	K_{idle}	=	The idle constant, note its range of values includes zero

Am = The Accelerators Modified Primary Signal (MPS) from the accelerators displacement sensor, after passing through its Primary Modification Module (PMM).

Note: that when the signal from the

accelerators sensor does not pass via a Primary Modification Module (PMM) then:

Am = Acc = The position of the accelerator

Note: Acc = 0, when at its rest position

Acc = 1, when at its maximum displacement

$FBRK_m$ = The Modified Primary Signal (MPS) from the force sensor on the brake pedal, after passing through its Primary Modification Module (PMM).

Note: that when the signal from the brakes sensor does not pass via a Primary Modification Module (PMM) then:

$FBRK_m$ = FBRK = The normalised force on the brake pedal.

i.e. FBRK = 0 if there is no force being exerted on the brake.

and = 1 if there is some "maximum" force being exerted on the brake.

Ravd is typically a constant, which acts to control the wheels RPM as Rc approaches zero, ie., spin on a spot mode (SOS).

A preferred value of Ravd is the average distance of the wheels from the vector datum point of the vehicle.

ie.,

$$Ravd = \frac{Rd_1 + Rd_2 + \ + \ Rdn + \ + \ Rd_N}{N}$$

where

$$Rdn = \sqrt{X\pm^2\Phi dn + Y\pm^2\Phi dn}$$

Where	N	=	The number of wheels on the vehicle.
Where	FR	=	The state of the Forward / Reverse Control Note: FR = 1 in the forward position FR = -1 in the reverse position.
	Rc	=	the distance of the centre of the circle (about which this vehicle is turning an arc) from the vector datum point. Note: Rc was calculated earlier.
	Kidle	=	A value from 0 to 1.0 which may set the speed of the vehicle when the accelerator is at its rest position etc.
	$X_{\pm\Phi dn}$	=	The X co-ordinator of wheel n in mode $\pm\Phi$, using vector datum point d.
	$Y_{\pm\Phi dn}$	=	The Y co-ordinator of wheel n in mode $\pm\Phi$, using vector datum point d..

Suitably, the angle of steer of the wheels is controlled as follows:

$$\phi\pm dn = SSW \times Tan^{-1} \frac{X_{\pm\Phi dn}}{Rc - Y_{\pm\Phi dn}}$$

Where

$\phi\pm\Phi dn$	=	The angle of steer of wheel n measured counter clockwise from the current major vector axis $\pm\Phi d$.
SSW	=	the sense of the current angular displacement of the steering wheel from its rest position RSW$\pm\Phi$. SSW = 1 when its counter clockwise i.e., to the "left" SSW = -1 when its clockwise i.e. to the "right"
$X\pm\Phi dn$	=	the X co-ordinate of wheel n in cruise mode $\pm\Phi d$ using vector datum point d.

$Y\pm\Phi dn$	=	the Y co-ordinate of wheel n in cruise mode $\pm\Phi d$ using vector datum point d.
Rc	=	the radius of the circle, about which this vehicle is turning an arc as may be measured along the vehicles minor vector axis $\pm\Phi d$. (Note, Rc is calculated earlier).

For a crab mode, the angle of steer ϕ_n may be controlled as follows:

$$\phi_n = K_C \times \sigma sw$$

Where K_C = The angular displacement constant (or function) of the angle of steer when in crab mode.

σsw = The angular displacement of the steering wheel, from its rest position.

Typically $Kc = K\sigma$ = The general angular displacement constant.

Hence:

$$\phi_n = K\sigma \times \sigma sw$$

The RPM of the wheels may be controlled as follows to provide a crab mode:

$$RPM_n = RPM_1 = RPM_2 = RPM_3 \text{ etc}$$

The control system may comprise three main components:

a) A software based control system herein referred to as a Motion Control Software, which may cause each of the vector wheel modules (or other wheel assemblies) to move in a specified manner. In particular, it may cause each to vector (in both speed and direction) so as to achieve optimum traction, road holding, etc. The system provides a number of different modes, which it may use to control the vectoring of all the vector wheel modules (or other wheel assemblies) in a systematic manner (and also the transition between modes) such that traction and roadholding advantages are realised;

b) A modular wheel assembly which, throughout the specification and is referred to as a Vector Wheel Module (VWM);

c) A steering override mechanism herein referred to as a Steering Override Mechanism, to allow the steering to be controlled by software. Yet which optionally provides a mechanical linkage such that should the software controlled steering fail, it would be able to override.

The invention can encompass the use of one or more of the above components, in a vehicle, aircraft, helicopter, structure, or machine, etc.

The vector wheel module can comprise two different versions being a:

a) High unsprung weight version, in this version no springs or other suspension items, are interposed between the wheel, and some of the heavy items within the vector wheel module such as the motor and the energy storage device (battery, ultracapacitor, etc.).

b) Low unsprung weight version, in this version springs or other suspension items are interposed between the wheel and some of the heavy items within the vector wheel module such as the motor, the energy storage device (battery, ultracapacitor, etc.).

TERMINOLOGY USED IN THIS INVENTION

Throughout the specification and claims the following terminology is used:-

EZE: A name to describe a vehicle using the methods and technologies of this invention.

Vehicle is used in this invention in a wide sense. It includes all types of vehicles, including aircraft, helicopters, machines, portable buildings and other structures that may on a permanent or otherwise basis use the invention described here to move.

Conventional Vehicle refers to those vehicles that at this date are commonly encountered on and off the road.

Wheel is used to refer to a road wheel that provides rolling contact between the vehicle and the surface over which it is travelling. Note the wheel in a vector wheel module is used in a wider sense and can also include a crawler track assembly.

Track this is used to refer to a crawler track assembly.

Steering Wheel is used to describe the operator's control used to steer the vehicle. It is consistently referred to as a steering wheel in an effort to avoid confusion (i.e. never as a wheel).

Steering Wheel is used here in a wide sense for any control used for steering the vehicle, i.e., it includes devices such as joysticks and other means.

Main Structural Frame (MSF) is used here to refer to the "chassis" or "hull" of the vehicle.

Vector Wheel Module (VWM) is used to describe the modular wheel (or track) assembly, which may contain a traction motor, a wheel (or track), a steering motor, an energy storage devices (such as a battery, ultracapacitor, etc.), and a computer means.

Twin Wheel Assembly Same Side (TWS) refers to a module or assembly which consists typically of a dual rotor motor driving two wheels on the same side of a vehicle.

Twin Wheel Assembly Opposite Side (TWO) refers to a module or assembly which consists typically of a dual rotor motor driving two wheels on the opposite sides of a vehicle.

Motion Control Software (VCS) is used to describe the software running in the motion control computer on the vehicle. Among other things this software typically controls the vectoring (in both speed and direction) of the VWM's (or other wheel assemblies) on the vehicle.

Motion Control Computer (MCC) refers to a computer usually located in the main structural frame of the vehicle and on which the motion controls software runs.

Vector control computer (VCC) is a computer usually located in the vector wheel module or wheel assembly. The VCC has overall control over the VWM, TWS or TWO. It may receive and carry out commands from the motion control software and transmits status back to the Motion Control Software running in the MCC.

Vector Control Software (VCS) refers to the software in the vector control computer.

Major Axis Zero (MAZ) is the name given to axis, which may be coincident with the normal major axis of the vehicle. MAZ is typically parallel to the normal major axis of the vehicle and lies in the same vertical plane. If a vehicle is say resting on a smooth horizontal surface (SHS), and the vehicle is loaded such that its body etc. is also horizontal., i.e., the suspension heights of all the wheels are the same. Then MAZ lies in a plane referred to here as the vector plane which is at height above the SHS equal to the current value of effective wheel radius plus the current value of the suspension height.

Note that typically the normal major axis of the vehicle may be at a height such as that it passes through the centre of gravity of the vehicle.

Note however when the vehicle is of irregular or variable shape, such that it may not have any obvious major axis or otherwise, then MAZ will typically be arbitrarily defined during the design or commissioning of the vehicle (also note that in the case of a disk shaped vehicle (or similar) that the major axis of such a vehicle, for the purpose of this invention, is as described above, (and not the normal one).

Also note that the "zero" in major axis zero, is to emphasise that one of the significant uses of MAZ is to provide a zero degrees reference for angular measurement.

Minor Axis Ninety (MAN) is the name used for the axis of the vehicle, which lies in the vehicles vector plane and, is at right angles to the vehicles Major Axis Zero (MAZ).

Centre of Vehicle (COV) is the name used for the point at which the vehicles Major Axis Zero (MAZ) and minor axis zero (IAZ) intersect. Note that its location along the major axis zero may be arbitrarily defined during the design or commissioning of the vehicle.

Vehicle Vector Plane (VVP). If a vehicle is resting on a smooth horizontal surface (SHS), and if all of the wheels are loaded such that all of the (typically independent) suspensions, associated with each wheel are at equal suspension height. Then the vector plane of the vehicle lies in a horizontal plane and its height above the SHS, in one form, is equal to the current value of the vehicles suspension height plus the current value of the vehicles effective wheel radius.

Major Vector Axis (AVA) of the vehicle is the major axis used by the Vector Control Software. Consider a vehicle in cruise 0° mode, where the AVA is the same as the major axis zero (MAZ) of the vehicle.

Major Vector Axis $\pm\Phi$ of the vehicle is the major vector axis in cruise mode $\pm\Phi$.

Also the angle of the major vector axis to the major axis zero (MAZ) of the vehicle is $\pm\Phi$.

Also the point at which the minor vector axis intersects the major vector axis of the vehicle is referred to as the vector datum point.

Consider again a vehicle in cruise mode 0° (ie $\Phi = 0°$), with its wheels pointing straight ahead, and if now this vehicles mode was changed to crab and the steering wheel was turned counter clockwise till the vehicle was travelling at 90° to its major axis, and the mode was switched back to cruise mode. Then the cruise mode is now cruise 90°, and the major vector axis is now referred to as major vector axis 90°.

Major Vector Axis $\pm\Phi d$ is used when the vehicle has multiple vector datum points, i.e., it refers to the major vector axis, when the vehicle is in cruise mode $\pm\Phi$, using vector datum point d.

Minor Vector Axis (IVA) of the vehicle, is at right angels to the major vector axis.

Minor Vector Axis $\pm\Phi d$ of the vehicle is the minor vector axis in cruise mode $\pm\Phi$, when using vector datum point d.

Vector Datum Point (VDP) is the name used for the point at the intersection of the major vector and minor vector axes of the vehicle.

Vector Datum Point d (VDPd) some vehicles may have multiple vector points, hence:

VDP_1 refers to the vector datum point 1

VDP_2 refers to the vector datum point 2

VDP_d refers to the vector datum point d

Vector Datum Radial θ (VDR) is a line which lies in the vector plane with origin at the vector datum point, and the position of which is specified by its angular displacement θ from the major vector axis, measured in a counter clockwise direction.

Vector Datum Radial $\Phi\theta$ is similar to above, but now refers to a line at angle Φ plus θ to the major axis zero (MAZ).

i.e., at angle θ to the major vector axis $\pm\Phi$.

Vector Datum Radial $\pm\Phi\theta d$ is similar to above and is used in vehicles with multiple vector datum points.

Hence VDR $\pm\Phi\theta d$ refers to the vector datum radial whose origin is at vector datum point d, and which is at angle θ to the major vector axis $\pm\Phi$.

Circle Centre, an arc of which, this vehicle is travelling (CCA). The CCA refers to the centre of the circle an arc of which the vehicle may be travelling.

Road Surface Plane (RSP) is used to refer to plane in which some, typically small, section of the road may be said to lie.

i.e. with a road on a flat horizontal surface, and if the road has zero camber, the RSP lies in the horizontal plane.

Minor Radial Axis of vehicle parallel to the road surface plane (MRA). Here MRA is used to refer to a line from the vector datum point, which lies in a plane parallel to the road surface plane, and also lines in a plane (at right angles to the RSP), in which the vehicles minor vector axis in lies.

Note when the roll angle of the vehicle (RAV) is zero, then the MARS is coincident with the vehicles minor vector axis.

Road Camber κ (kappa) is used to refer to the angle between a line lying in the surface of the road, (which is a radius of the circle, an arc of which the vehicle may be travelling), and the horizontal plane.

i.e., If a road has an angle of camber κ, then the RSP of that (typically small) section is at angle κ to the horizontal plane.

Roll angle of vehicle ρ (rho) is used to refer to the angle between the vehicles minor vector axis and the Road Surface Plane.

Vector Connection Point (VCP) is the name given to the point at which the vector wheel module is connected, i.e. plugs etc for electrical/data etc connection to the VWM, TWS or TWO. Also bolts or a quick release mechanism, etc. may be used for the mechanical aspects of the mounting.

Wheel Co-ordinates X, Y, Z. One of the methods, is to specify the co-ordinates of the wheels in terms of their Cartesian co-ordinates X, Y, Z.

X co-ordinates are measured along the major vector axis ±Φd.

Y co-ordinates are measured along the minor vector axis ±Φd.

Z co-ordinates are measured at right angles to the vector plane.

Wheels Co-ordinates ±Φ are the co-ordinates of a point on the major axis of the wheel when the vehicle is in cruise mode ±Φ, i.e., X±Φn, Y±Φn, Z±Φn.

Wheel Co-ordinates ±Φd, may be used when the vehicle has multiple vector datum points, i.e., when it is in cruise mode ±Φ, with vector datum point d, then the co-ordinates of wheel n are, X±Φdn, Y±Φdn, Z±Φdn.

i.e., the wheel co-ordinates ±Φ of wheel n are referred to here as X±Φdn, Y±Φdn, Z±Φdn. More specifically these are typically the co-ordinates of the point PVPdn at the intersection of a line which is at right angles to the vector plane, and passes through the centre of the wheel road contact area.

This line is referred to here as the standard wheel road contact line (SWR). The SWR may be a minor axis of the wheel.

Note:

a) When a vehicle is in cruise mode $\pm\Phi$, then as discussed above, the co-ordinate system used for Cartesian measurement is at $\pm\Phi$ to the vehicles major axis zero (MAZ).

b) When the vehicle is in cruise mode $\pm\Phi$, using vector datum point d then:

$X\pm\Phi dn$ is the X component of the point PVPdn where the SWR of wheel n intersects with the vector plane, when the vehicle is in cruise mode $\pm\Phi$ and vector datum point d. This point is referred to as the point in the vector Plane PVPdn.

$Y\pm\Phi dn$ is the Y component of the point PVPdn, where the SWR of wheel n intersects with the vector plane, when the vehicle is in cruise mode $\pm\Phi$ and vector datum point d.

$Z\pm\Phi$ is the distance that the vector plane is above a reference point WRPn on the major axis of wheel n. When the vehicle is in cruise mode $\pm\Phi$. (And where $Z\pm\Phi$ is the Z component, i.e., measured at right angles to the vector plane.)

Note that the wheel reference point (WRP) of wheel n, typically is at the intersection of its major and minor axes.

Note that normally Zn is independent of the cruise mode and the, vector datum location, and can be simply written as Zn.

c) When the vehicle is in crab mode, the co-ordinates are as for cruise mode 0°.

d) Note that in most of the methods of this invention, referred to as the fundamental methods, that in the first instance only the $X\pm\Phi$ and $Y\pm\Phi$ components are used, in calculating the wheel RPM and angle of steer.

e) However certain versions of the VWM's etc., (i.e., swinging arm etc.) $X\pm\Phi$ and $Y\pm\Phi$ may be a function of the suspension height $Z\pm\Phi$. Where this function is significant, a correction may be made to $X\pm\Phi$ and $Y\pm\Phi$ depending on the suspension height $Z\pm\Phi$.

f) Hence note that in the methods referred to as the fundamental methods of this invention, that typically $Z\pm\Phi$ is not used (it is typically only any change in $X\pm\Phi$ and $Y\pm\Phi$, caused by a change of $Z\pm\Phi$, which is of interest).

Suspension height of wheel n in mode $\pm\Phi d$ is referred to as $Z\pm\Phi dn$. As discussed above it is the distance, the vector plane, is above the point at the intersection of the wheels major axis, and the wheels standard wheel road contact line (SWR) which is at right angles to the vector plane.

Standard wheel road contact line (SWR) is a line at right angles to the vehicles vector plane which passes through the centre of contact of the wheel with the road, when the vehicle is resting on a smooth horizontal road, and it is loaded such that all of its suspension heights are equal, i.e., the vehicles vector plane lies in a horizontal plane. Note that typically the SWR intersects with the wheels major axis.

Wheel Contact Line (WCL) refers to a line at right angles to the vehicles vector plane, and passes through the center of the wheel road contact area.

Undulating surface operation, refers to the operation of a vehicle over an undulating surface etc. where the suspension height $Z\pm\Phi$ is varying.

When the vehicle is operating over an undulating surface etc., the variation in wheel RPM, to maintain optimum traction, may be handled, typically by an undulating surface operation, secondary software module in the MCC, or in the VCC.

Polar Wheel Co-ordinates Rdn, θdn. Another of the methods, which is particularly applicable when the vehicle has a number of cruise modes etc., is to specify the location of the wheels in terms of their polar co-ordinates.

The polar co-ordinates are located in the vehicles vector plane, the pole being the current vector datum point n. Specifically Rdn, θdn specify the location on the vector plane of the point PVPdn, at which the SWR of wheel n intersects the vector plane, when the vehicle is in cruise mode $\pm\Phi$, and using vector datum point d. Hence:

Rdn specifies the distance of wheel n from vector datum point m.

$\theta\pm\Phi$dn specifies the angle that the wheel is located at measured counter clockwise.

i.e., it is at angle θdn from the current major vector axis $\pm\Phi$.

Hence it is at angle (θdn$\pm\Phi$) from the vehicles major axis zero.

Angles, generally the following convention is followed:

α alpha	=	is the angle of the major vector axis of the vehicle to a horizontal plane.
β beta	=	is the angle of the minor vector axis of the vehicle to a horizontal plane, note that typically $\beta = \kappa - \rho$.
σ sigma	=	the angular displacement of the steering wheel from its rest position.
ϕphi	=	the angle of steer of the vehicle wheels.
ΦPHI	=	the angle of the current cruise mode.
κ kappa	=	the angle of camber of the road.
ρ rho	=	the angle of roll of the vehicle.
θ theta	=	the angle of the polar co-ordinate.
δ gamma	=	for general use.

Note: That typically all work has used degrees, however it may equally well use radians.

Cruise is used here to describe the normal mode of operation and in particular the mode of steering that maybe similar to that used for example in a vehicle similar in appearance to a conventional four wheel steer vehicle. When the steering wheel is rotated in a clockwise direction the front wheels are steered through a angle in a clockwise direction (looking down on the vehicle) and the rear wheels typically in an anticlockwise direction. Cruise mode in this invention specifically refers to the mode where if the steering wheel is turned in one direction, that the wheels forward of the minor

vector axis steer through some angular displacement in the same direction (when looking down on the vehicle) and the wheels rear of the minor vector axis steer through some angular displacement in the opposite direction.

Cruise mode $\pm\Phi$d, refers to operation in cruise mode $\pm\Phi$, and using vector datum point d.

As used here the cruise mode, of the vehicle, indicates the general angle $\pm\Phi$ at which the vehicle is travelling, relative to its major axis zero.

i.e.	(+)	Is due to a counter clockwise movement of the steering wheel, while in crab mode.
	(-)	Is due to clockwise movement of the steering wheel, while in crab mode.
	Φ	Is an angle from 0° to 360°.
	d	Refers to the current vector datum point.

Typically cruise mode $\pm\Phi$d refers to the angular displacement of the wheels to the major axis of the vehicle, when the cruise / crab control is moved from crab to cruise, i.e. as the vehicle enters cruise mode $\pm\Phi$d, then $\pm\Phi$ refers to the angular displacement of the wheels (not the steering wheel) in degrees from the major axis of the vehicle, when this cruise mode $\pm\Phi$ was entered. The cruise mode 0° is a special case, and the ± has no valid meaning, hence it may be written as cruise mode 0° or simply as cruise mode 0° or cruise 0°.

Consider a vehicle travelling in cruise mode 0° along a road. Consider it is slowed down or stopped, near a parking space with its wheels all at or near 0°, and consider if its cruise crab control is now switched to crab, and the steering wheel rotated counter clockwise, and the acceleration pressed such that the vehicle moves to the left into a parking space, its mode of travel is described here as crab (+) or crab left, say that the vehicle now stops or slows down with its Wheels at 90 degrees to the vehicles major axis. If the operator now moves the cruise/crab control back to its cruise position, the mode of operation is now referred to in this invention as cruise mode 90°, or simply as cruise 90°.

Some versions may restrict the cruise modes to only cruise 0°.

Some versions of this invention may restrict the modes to, for example, cruise 0°, cruise 30°, cruise –30° and crab. Other versions may restrict the modes to cruise 0°, cruise 90°, cruise –90° and crab. Other versions may offer a smaller or wider range of cruise mode $\pm\Phi$operation.

Some versions typically intended for industrial or mining applications etc, may automatically or otherwise cause the operators seat, and at least some of the operators control, and displays, to move to the current angular setting of the cruise mode $\pm\Phi$.

A display device, using digital or analogue techniques, may be provided such as to show the angle of cruise mode. This display will typically retain its display unchanged as the vehicle travels

along curves in a road or, even when switching to crab to drive sideways, it typically only changes when the vehicle exists a crab mode, and enters a cruise mode of different angle.

Typically, the vehicle of this invention uses, crab mode, as an intermediate step, to change between cruise mode of different angular settings.

Some versions of the vehicle may have a control on which the angle of the desired cruise mode $\pm\Phi$ can be specified, such that the correct cruise mode $\pm\Phi$ may be entered.

Crab is used here to describe the mode of steering, which could be used when driving sideways into for example a parking space. Note that in this invention it is used specifically to describe the mode of controlling the vehicle where typically all the wheels are steered through an angular displacement in the same direction, and where the angular displacement of the wheels is the same sense (when looking down on the vehicle) as that of the steering wheel, i.e., where all of the wheels are parallel, or at least substantially so.

Note that in crab mode, there may be only the one crab mode, however, note that:

Crab (+) may be used to describe the mode, when the steering wheel is displaced in a counter clockwise direction from its rest position.

Crab (-) may similarly be used to describe the mode, when the steering wheel is displaced in a clockwise direction.

Cruise Crab Control (CC or CCC) is the name used in this invention to describe the operators control, used to select between cruise mode and crab mode.

CC Transition Phase (CCT) is used to describe the operation during the transition from cruise mode to crab mode and vice versa.

In the first instance the Wheels on a vehicle should be all at the same steer angle (i.e., substantially parallel) as the vehicle changes between cruise and crab mode and vice versa. It is the purpose of the CC transition phase to ensure that this condition is satisfactorily met, such that the mode change from cruise to crab and vice versa, can take place. Typically, it may for example, also force the vehicle to slow down (or even stop) such that the mode change can occur in a safe manner etc.

Note that some vehicles may not use the CCT mode at all.

Forward (or Preferred) Direction in a vehicle of shape similar to that of a conventional vehicle, it has the normal meaning in the cruise mode 0°. If the mode changes for example to cruise 90°. Then the forward direction is typically at 90° to the major axis of the vehicle. More specifically the Forward (or Preferred) direction is the movement in a positive direction of $X\pm\Phi$.

Note that in a vehicle of irregular or other shape, it may not be obvious. Typically in these cases the forward direction may be specified during design or commissioning etc.

Reverse Direction, simply refers to the direction opposite to the Forward (or Preferred) direction.

Rest position of the Steering Wheel (RSW) is used in this invention to describe the position of the steering wheel, when its angular displacement sensor (typically capable of sensing angles in excess

of 360°) indicates zero. Note that the steering wheel sensor is adjusted such that the RSW typically occurs when the vehicle is travelling straight ahead, with all wheels parallel while in cruise mode 0°.

RSW $\pm\Phi$ refers to the rest position of the steering wheel when the vehicle is in cruise mode $\pm\Phi$.

Rest Position of the Vehicles Wheels (RPW), is used to describe the position of wheels, when they are substantially parallel to the major axis zero of the vehicle.

Free/Fixed Control (FFC) is a control which may be used to lock the angle of steer of some of the wheel when in the fixed position, and unlocks those wheels when in the free position.

Forward/Reverse Control, (FRC) this control allows the operator to select movement in a forward or reverse direction. Note in some form of the invention, this control and the cruise/crab control and the ratio selected (if this option is provided) maybe all integrated into one.

Ratio select control (RSC), some forms of the invention provide two or more ratios in the power transmission between the polyphase traction motors and the wheel. This control is used to select the required ratio. Note that in one form of the invention, the slave control computer in each VWM, TWS or TWO controls the speed of the polyphase traction motor, during the change such that it synchronises the gears etc, before they engage so as to provide, a smooth change of ratios without any "gear clashes" etc.

Tight Loose Control (TLC) or pseudo gear change control. This control typically does not have anything to do with the ratio of the power transmission (typically interposed between the polyphase traction motor and the wheel). Instead the TLC controls the time constants, and other parameters associated with the overall control of the polyphase traction motors acceleration / deceleration characteristic, typically via a TLC primary software modification module within the vector control software. The TLC maybe integrated into a FRC / RSC.

Action Stick (AS) is the name used for a control, which maybe somewhat similar to a gear stick in a conventional car, but into which some or all of the above, and other, controls maybe integrated.

ie., the action stick may contain :-

(1) Forward Reverse control.

(2) Ratio Select control (if relevant).

(3) Tight Loose control, (i.e. the pseudo gear change control)

(4) Cruise Crab control.

Joy Stick (JS) is the name used for a control which may have a ball joint or similar, such as to allow, the pivoting of it in any direction, similar to that used in some aircraft. Typically it maybe used here in place of a steering wheel, the accelerator, and the forward / reverse control. Other controls may also be integrated into it.

Max Stick (MS) is the name used for control which may have the functions of a joy stick and a action stick, and others integrated into it. The basic shape of a max stick maybe similar to a joy stick.

Typically hand movements control the steering and speed. Finger controls maybe provided for other functions including those which otherwise may have been provided by an action stick.

Mach Stick, another name for a Max Stick.

Accelerator is used there in a wide sense for any controls, typically foot operated, which controls the vehicles speed. Other vehicles may integrate this control into for example a joy stick etc., where it is hand or finger operated.

Foot brake is used in a wide sense (it may be hand or otherwise operated) so as to cause a braking action on the wheels. Typically it will consist of a pedal or other foot operated means, similar to that of the foot operated brake pedal in a conventional vehicle.

Hand brake is used in a wide sense (it may be operated by means other than hand). Typically it will be similar to the handbrake in a conventional vehicle, typically it will provide a means of applying one or more of the braking methods, should the foot brake fail. Typically it may be used to hold the brakes on, when the vehicle is parked etc.

Steering Override Mechanism (SOM) is used to describe a mechanism which may be fitted to vector wheel module, TWS or TWO such that, most of the advantages of software controlled steering are retained, yet providing a means of providing a mechanical linkage (to at least some of the wheels) such that should a fault occur when the vehicle is travelling at speed, the steering override mechanism provides a backup to reduce the possibility of accidents.

Polyphase Motor is the name used to describe the motors typically used for the traction motor, the steering motor etc in each VWM. These motors may have two or more phases, and typically two or more poles. Typical examples include say a 3 phase, 4 pole induction motor, 2 or more phase stepper motor, a "Brushless DC motor" (BLDC), typically with 3 or more phases.

Polyphase Traction Motor (PTM) is the name used for the polyphase motor which drives the wheel typically via a power transmission.

Direction of Rotation of a shaft etc at right angles to the vehicles major axis zero and which lies significantly in a plane parallel to the vector plane. Direction of rotation has a specific meaning and is typically used here to describe the direction of rotation of the polyphase traction motors and their associated power transmissions and the wheels of the vehicle, etc.

The direction of rotation is that which would be seen when standing on the left hand side, external to the vehicle and looking "through the vehicle with x-ray eyes".

Consider, for example, a four-wheel vehicle, similar to that of a conventional four-wheel vehicle.

Hence, according to this convention, all four wheels will be said to turn counterclockwise when the vehicle is travelling in a forward direction.

Direction of Rotation of a shaft etc which is substantially vertical to the, vector plane. The direction of rotation of such a shaft etc is always that seen when looking down on the vehicle, from above.

Note that for the purpose of this document a steering wheel is considered as a substantially vertical shaft.

Torque Sense of a Motor (TSM): some of the motors such as the polyphase traction motors may at some time act as alternators (i.e., a source of electrical energy). A motors torque is said to be positive, if the motor is acting as a motor. The torque is said to be negative, if a motor is acting as a alternator.

Revolutions Per Minute (RPM) is typically used here to specify the rotational speed of a shaft or wheel etc.

Clockwise (CW), and counter clockwise (CCW) are typically used here to specify the direction of rotation of a shaft or wheel etc.

Lineal Velocity of a wheel, typically this is specified here in terms of the lineal velocity of the point where the wheels major axis and minor vertical axis intersect, i.e., the wheel reference point (WRP).

Lineal position of a wheel, typically this is specified here again in terms of the position of the point where the wheels major axis and vertical minor axis intersect (WRP).

Tyre Scrubbing, is used to here to refer to what may occur when the horizontal component of a wheels lineal velocity is not solely at right angles to the major axis of the wheel.

i.e. tyre scrubbing is said to occur when the lineal velocity of a wheel has a component, which is along the major axis of the wheel.

Unloaded Wheel Radius (UWR), is the radius of a wheel when it is unloaded.

Effective Wheel Radius (EWR), is used here typically to refer to the distance of the major axis of a wheel (typically loaded), from a smooth planar surface, on which it is running. Typically it is measured along a line from the wheels reference point (WRP) which is at right angles to the smooth surface.

Wheel Reference Point (WRP): is typically used here to refer to the point at which the wheels major axis, intersects with its minor axes.

Wheel Reference Point Vector Plane (PVP), is a point at the intersection of the wheels reference line (WRL) and the vector plane.

Low Unsprung Weight (LUW) is used here to refer to a wheel module or assembly in which suspension elements such as springs etc. have been interposed between the wheel and some of the potentially heavy items associated with it, such as the polyphase traction motor, batteries etc. I.e., the weight "below" the springs etc. may be said to be "low"

High Unsprung Weight (HUW) is used here to refer to wheel modules or assembly where springs have not been interposed between the wheel and some of the heavy items. I.e., the weight "below" the springs etc. may be said to be "high".

Serial Suspension is used here, where there may be two or more groups of suspension elements (such as springs, actuators etc.) connected in series. I.e., typically the same component of the vehicles weight may be carried by both or all of these groups of suspension elements, i.e., a body height adjustment ram, which is mounted above a spring / shock absorber. Hence in the terminology used here the ram may be said to be in series with the spring / shock absorber combination.

Axial Steering Arrangement (ASA) is used here to describe the arrangement of the bearings, ball joints etc. on which the wheel may pivot, such as to allow it to be steered. Where the axis of (or through these bearing or ball joints etc.) typically passes substantially through the center of the contact area of the wheel and the road.

Data Communication Network (DCN) is used to refer to the network of fibre optic cables, conventional cables, infrared links etc, which are used to communicate between the Motion Control Computer and the vector wheel modules and the various sensors, transducers and other equipment etc located throughout the vehicle.

Main Power Bus is the name given to the electrical bus used to distribute electrical energy within the main structural frame of the vehicle. Basically it connects the power sources (i.e. fuel cells, solar cells, alternators, batteries, etc) to the computers, vector wheel modules and other equipment.

Energy Storage Device, as used herein refers to a battery, supercapacitor or ultracapacitor and the like which is able to store a significant amount of electrical energy – typically sufficient to power the device, with which it is associated for at least a second or two, or a minute or two, and in some cases for longer, such as an hour or a day.

VWM Power Bus is the name used for the power bus used to distribute electrical energy within each vector wheel module. In particular it typically takes electrical energy from a connector at the vector connection point and distributes it to the energy storage devices (batteries, ultracapacitors, etc.), motors and or their polyphase inverters/controllers computer means etc in the VWM or wheel assembly.

Primary Data Signal (PDS). Typically these are input signals to the Motion Control Software (MCS) which runs in the Motion Control Computer.

Consider a four wheel vehicle with a regular arrangement of wheels, similar to that of a conventional vehicle. Then an example of a primary data signal is the signal from the sensor attached to the accelerator, which indicates the displacement of the accelerator. This signal is typically used by the VCS as the primary specification of the RPM at which the wheels on the vehicle are going to be forced to rotate at.

Secondary Data Signal (SDS). Typically these are output signals from the Motion Control Software (MCS).

Consider an example of a vehicle similar to described above. Then examples of secondary signals are the four signals output from the MCS to the Vector Control Computer (VCC) in each of the VWM's which specify the RPM at which each of VWM's etc is to force its wheel to rotate at.

Consider if the above vehicle was travelling in a straight line and if functions such as wheel diameter profile are switched off. Then each of the secondary data signals output from the MCS which specify the RPM of each wheel, may be the same, and may also be the same as the primary data signal from the displacement sensor attached to the accelerator.

Consider if the vehicle was now travelling around an arc of a circle, then the two secondary data signals to the two "outside" wheels will specify a greater RPM than the two secondary data signals to the two "inside" wheels.

Consider now if for example the wheel diameter profile feature was enabled, and if for example all the wheels are not exactly the same diameter, then all of the four secondary data signals which specify their wheels RPM, may be different.

Tertiary Data Signal (TDS). An example of these may be the output data signals from the Motion Control Computer (MCC) in a VWM to its polyphase Inverter / Controller (for the polyphase traction motor) which specifies the RPM at which the wheel is to be forced to rotate.

Modified Primary Signal (MPS) is the terminology used to refer to a primary signal, such as that from the displacement sensor on the accelerator after it has passed through a Primary Modification Module (PMM) and been modified etc according to say the position of the TLC (Pseudo Gear Change) Control.

Modified Secondary Signal (MSS) is the terminology used to refer to a secondary signal, such as the RPM commands from the VCS, after they have passed through a Secondary Modification Module (SMM) and been modified for example by the Wheel Diameter Profile (WDP).

Primary Modification Module (PMM) is used to refer to a hardware and or software module which may be interposed between the source of a primary signal (i.e., a sensor etc) and the Motion Control Software (MCS). Note that a PMM may simply exist as a software module within the MCS which modifies the primary data signal before it reaches the MCS proper.

Secondary Modification Module (SMM) is similarly used to refer to a hardware and or software module, which is interposed between the MCS and the destination of the secondary data signal. Again it may simply exist as a software module within the MCS.

In another form, the invention resides in a vector wheel module which has a ground engagible wheel (or track), a first drive means to rotate the wheel (or track), a second drive means to steer the wheel (or track), an energy storage device to at least partially supply the drive means, an attachment means to attach the vector wheel module to a vehicle, and a spring or other suspension element

interposed between the wheel (or track) and some heavy items described above such as motors, energy storage devices (batteries, ultracapacitors, etc.) so as to reduce the unsprung weight of the vector wheel module.

In another form, the invention resides in a vector wheel module as above wherein the spring or other suspension element is not interposed between the wheel (or track) and some heavy items such as motors, energy storage devices (batteries, ultracapacitors, etc.), etc., such that this from may be said to have a higher (or high) unsprung weight.

In another form, the invention resides in a vector wheel module (as first described above) which does have a spring or other suspension element interposed between the wheel and some of the heavy items, but now has an additional spring or other suspension elements, including suspension height adjustment device interposed between them and the chassis connection point. Hence this form may be said to have serial suspension elements.

In one form where serial suspension elements are used, that one of these elements may consist of a height adjustment mechanism or component such as hydraulic or pneumatic ram or bag or a linear electric actuator etc.

In another form similar to above these height adjustment mechanisms or components may be integrated in to one or more of the components forming this serial suspension, i.e., they may be integrated into a strut or shock absorber etc.

In one form similar to above, a sensor may be provided to measure the height of the suspension, and provide details of such in the form of electric signals of analogue or digital form.

In one form one or more accelerometers may be provided, within the vector wheel module and or main structural frame of the vehicle. These may be oriented substantially in a plane parallel to the surface on which it rests, and at right angles to the direction of travel such as to sense acceleration, in both magnitude and direction, acting sideways on the vehicle as it turns through a curve or corner, i.e., an arc of a circle.

In one form similar to the above forms, one or more software and or hardware controllers may be provided such as to control the height of one or more of these suspension height control devices such as to reduce the roll of the vehicles body i.e., typically increase the height on the outside wheels, and decrease the height on the inside wheels.

In one form the accelerometers, and software and or hardware controllers may be contained within the vector wheel module. They may also provide status of the acceleration, including its sign, and or suspension height to a computer means located external to the vector wheel module. Additionally they may also receive data commands from the other computer means which may also control the suspension height devices.

In one form, particularly applicable to that using a suspension height sensor. Here the controller may be using the height of the suspension, as indicated by the sensor, as a measure of the bodys roll

during cornering, and may contain an algorithm, basically consisting of a negative feedback loop which acts to maintain the height of each wheel constant. In this form the time constants associated with this feedback loop may be such as to provide a high loop gain at lower frequencies (i.e., longer period) such as may occur when the vehicle is cornering. Also these loop time constants may be such as to provide a low loop gain at higher frequencies (short period) as may occur when the wheel hits a pot hole.

Hence the result may be a system which with a vehicle on a smooth road, travelling at some speed on a corner, the loop acts to tend to correct the tendency of the vehicles body to roll, while if a wheel hits a pot hole, it allows the springs to cause the wheel to tend to follow the profile of the hole with little or no change occurring in the actuators, rams etc.

In one form similar to above, the "DC" or "zero frequency" or other loop gain may be a function of the wheels, or the vehicles speed.

In another form similar to above, the value of, at least some, of the time constants associated with the loop may be a function of the wheels, or the vehicles speed.

In another form similar to the above, both the loop gain, and also the value of the time constants may be a function of the wheels, or the vehicles speed.

By having a modular self contained wheel (or track) assembly system such as the vector wheel module as described above, the module may be removed from the vehicle should a fault occur, and repaired, or replaced with a another vector wheel module. This makes maintenance of vehicles having such vector wheel modules significantly easier and quicker, and allows for the mass production of larger quantities of the vector wheel modules due to typically all of the VWM's used on a vehicle being more or less identical.

By having a vector wheel module as described above, more versatility is possible with the suspension assembly and the steering arrangement. For instance, the vector wheel module may not require a mechanical drive link to the vehicle for the transmission of tractive torque. Hence, it is a simpler task to design a suspension which may be used to increase or decrease vehicle ground clearance in a simple yet reliable manner. Additionally, it is possible to steer all of the wheels, even when there is a large number, and or they are located on the vehicle remote from the vehicles operator. It is also possible for the wheel to steer or pivot through a larger range of angles. For instance, the second drive means may form part of the wheel assembly and may steer or pivot the wheel possibly through 90°, 180° or even greater angles of steer. This in turn allows the vehicle to turn through tight corners and park in narrow spaces, such as driving sideways (i.e. crab style) into small parking spaces.

The vector wheel modules, and other wheel assemblies, may be used on a wide range of vehicle including cars, buses, trucks, road trains, lorries, tractors, military vehicles, helicopters, aircraft, spacecraft, robots and autonomous vehicles, including two or three wheeled vehicles, etc. The

invention is particularly suited to vehicles requiring a large number of wheels that may be fitted in a regular (or irregular) pattern, and may be located on or near the external surfaces of the vehicle or on outriggers, or underneath the vehicle and also vehicles of variable shape and or geometry, such as, mining and earth moving equipment, cranes, etc.

The wheel of the vector wheel module may be sized and shaped to suit the particular vehicle on which vector wheel module (or other wheel assembly) may be used. The wheel may have a central hub and a peripheral tyre, for instance a pneumatic tyre. Solid wheels or composite wheels are also envisaged for other applications. Track versions of the VWM have a crawler track type mechanism in place of a wheel.

Note that versions of the vector wheel module which use track instead of a wheel, that the track would typically be less than fifty percent of the overall vehicle length and in most cases be some significantly smaller percentage of the overall vehicle length.

The vector wheel module may have more than one ground engagible wheel and this may be required for extra grip or to support heavier loads. However, generally it is preferred that the vector wheel modules consist of a single ground engageable wheel, and if heavier loads are to be supported, a greater number of the vector wheel modules can be fitted.

Two versions of the wheel assembly (other than the VWM's) are of particular significance, one of these is referred to as a twin wheel module opposite side (TWO), which has two wheels, one of which is on each side of the vehicle (hence it has wheels on opposite sides).

Another is referred to here as twin wheel module same side (TWS), where both of the wheels are on the same side, and typically both of which are the same distance from the major axis of the vehicle.

The drive means of the VWM, TWS or TWO is typically a polyphase electric motor although it is envisaged that a hydraulic motor (powered by a hydraulic pump, driven by a polyphase electric motor) could also be used in some circumstances. A gearbox or gear train and or belts and pulleys, and or chain and sprockets or transmission of sorts or a combination of these including ones which include a gear change (or other ratio change mechanism) may be provided to couple the electric motor to the ground wheel, or track assembly.

The second drive means may also consist of an electric motor (typical a polyphase electric motor) or an electric rotary or linear actuator or a hydraulic motor or a hydraulic rotary or linear actuator (powered by a hydraulic pump which is driven by a electric motor) which may be powered by the same power source. The second drive means functions to steer or pivot the wheel, or track assembly.

The wheel (or track) in the vector wheel module (or other wheel assemblies) may be steered in a number of ways. One preferred way is to have the wheel (or track) supported by a first support or frame, which can pivot relative to a second support or frame, with the second support or frame attached to the vehicle (or via a suspension). The second drive means can cause the first support or frame to

pivot relative to the second support or frame, and allows versions to be designed to steer through some fraction of a revolution or even through multiple revolutions, as the application may dictate.

The wheel (or track) in the vector wheel module (or other wheel assemblies) can be steered in a number of ways. Another preferred way is to have the wheel (or track) supported by a first support or frame, which can pivot relative to a second support or frame, with the second support or frame attached to a third support or frame via a dampened elastic suspension mechanism to the vehicle (or the vehicles suspension). The second drive means can cause the first support or frame to pivot relative to the second support or frame, and allows versions to be designed to steer through some fraction of a revolution or even through multiple revolutions, as the application may dictate.

In another form of the vector wheel module (VWM) or other wheel assembly similar to that described above, may include a steering override mechanism (SOM).

In another form of the VWM or other wheel assembly, similar to above, may include a steering lock mechanism (SLM) such that the angle of steer of the wheel may be locked at a fixed angle on a temporary or permanent basis.

In another form of VWM or the wheel assembly, similar to the above, which may include a steering lock mechanism (SLM), but may not include a steering override mechanism (SOM).

In another form of the VWM or other wheel assembly similar to the above, but which does may include any electrical or electronic or computer means such as to steer it, and may not include a SOM, but may have a means of permanently or otherwise, locking the angle of steer.

In another form of the VWM or other wheel assembly similar to the above, but which does not include a traction motor (polyphase or otherwise).

FUNDAMENTAL METHODS

In one form of the invention, the methods used by the software in this invention to Control the angle of steer and RPM of each of the vector wheel modules (or other wheel assemblies) include the following:

1) In a preferred embodiment each wheel may have its own steering motor and or steering mechanism and linkage, etc., such that each wheel may in the first instance be forced to steer at a unique angle.

2) In a preferred embodiment each wheel may have its own polyphase traction motor, such that in the first instance each wheel may be forced by the polyphase traction motor to turn at a unique RPM irrespective of whether the vehicle is accelerating, travelling at constant velocity or deceleration (braking) or at least over a significant part of its RPM range. This is possible because the polyphase traction motor, may not only acts as a motor, but may also act as an alternator to extract energy from the wheel (regenerative braking) and is hence able to control instant by instant the RPM of the wheel in both sign and magnitude without the use of friction braking (at least over much of the operating speed

range). Hence the speed of each wheel may be uniquely controlled within tight limits, with a minimum of energy wastage due to friction braking.

3) In a preferred embodiment each vector wheel module, or other wheel assembly may receive a unique command from the Motion Control Software which specifies instant by instant the angle of steer and RPM of its wheel (or wheels), such that as detailed above its wheel is forced to steer at that angle and forced to turn at that RPM.

4) In a preferred embodiment, as a result of the above the Motion Control Software may implement a method of software based control of the wheels such as to achieve optimum traction and roadholding with a minimum of tyre scrubbing and wear. The method uses two principal modes of steering and general control of the wheels, referred to here as cruise mode and crab mode. The method provides a system in which the steering and speed of each wheel is controlled in a systematic manner such that optimum traction and roadholding may be maintained throughout both of these modes, including the transition phase between modes.

5) In a preferred embodiment, one of the methods provides a number of different cruise modes. These are referred to here under the general title of cruise mode $\pm\Phi$. Where the $\pm\Phi$ refers to the angle of steer of all the wheels (i.e., they are all significantly parallel) when the vehicle entered this cruise mode $\pm\Phi$.

6) In a preferred embodiment, the method also provides one or more crab modes, which among other applications, may be used as an intermediate mode which allows the vehicle to change between one cruise mode $\pm\Phi$, and another i.e., between say cruise mode $\pm\Phi_1$ and cruise mode $\pm\Phi_2$.

7) Another of the methods is to locate an axis referred to here as the vehicles major axis zero (MAZ) which typically is parallel to the vehicles major axis, and lies in the same vertical plane as the vehicles major axis. More specifically they may lie in the same vertical plane, when the vehicle is resting on a smooth horizontal surface (SHS) and it loaded such that the angle that the body, or form of the vehicle resides in, is at is preferred or normal orientation to the smooth horizontal surface (SHS). When however the vehicle is of irregular or other form, such that it may have no obvious major axis, or where its major axis may not suit the purpose of this invention, then the major axis zero (MAZ) of this from may be arbitrarily defined during design or commissioning etc.

8) Another of the methods is to locate another axis referred to here as the minor axis ninety (MAN), which when the vehicle is resting on a smooth horizontal surface (SHS) as described above, the vehicles minor axis ninety (MAN) lies in the same horizontal plane as its major axis zero (MAZ).

Another of the methods is to locate the minor axis ninety (MAN) at right angles i.e., ninety degrees to its major axis zero (MAZ).

Another of the methods is that the point of the intersection of these two axes may be referred to as the centre of the vehicle (COV).

9) Another of the methods is to locate a plane referred to here as the vehicles vector plane (VVP) in the plane of its major axis zero and minor axis ninety.

10) Another of the methods is to locate, an axis referred to here as the vehicles major vector axis (MVA), which lies in the vehicles vector plane (VVP), and may be coincident with the vehicles major axis zero.

Another of the methods is to locate an axis referred to here as the vehicles major vector axis $\pm\Phi$, which also lies in the vehicles vector plane, and is at angle $\pm\Phi$ to the vehicles major axis zero (MAZ). A positive value of Φ indicating that Φ is measured in a counter clockwise direction when looking down on the vehicle from above.

Another of the methods is to use the major vector axis $\pm\Phi$, as the reference for angular measurement in the vehicles vector plane when the vehicle is in a mode referred to here as cruise mode $\pm\Phi$.

11) Another of the methods is to locate an axis referred to here as the minor vector axis (IVA) which lies in the vehicles vector plane (VVP) and which is at right angles to the vehicles major vector axis.

Another of the methods is to locate a axis referred to here as the vehicles minor vector axis $\pm\Phi$ which lies in the vehicles vector plane (VVP) and is at right angles to the vehicles major vector axis $\pm\Phi$.

12) Another of the methods is to locate a point referred to here as the vector datum point (VDP), at the intersection of the vehicles major vector axis and its minor vector axis.

Another of the methods is to locate multiple minor vector axes $\pm\Phi$, and these are referred to here as minor vector axis $\pm\Phi$d, where typically d may be any integer 1 or larger.

Another of the method is to locate multiple vector datum points, referred to here as vector datum point d, which are at the intersection of the vehicles minor vector axis $\pm\Phi$d and its major axis zero.

13) Another of the methods is to locate the point at the intersection of the minor vector axis and the major vector axis, referred to here as the vector datum point within the vehicle or external to it.

14) Another of the methods is to locate the position of the vehicles wheels, and or other components of the vehicle, and or other components or accessories, on a system of Cartesian co-ordinates where:

a) The X and Y components lie in the vector plane as described previously, their origin being located at the related vector datum point, hence:

b) X $\pm\Phi$dn is the X component of the location of wheel n etc., is measured along the major vector axis $\pm\Phi$d, from vector datum point d.

c) Y$\pm\Phi$dn is the Y component of the location of wheel n etc., is measured along the minor vector axis $\pm\Phi$d, from vector datum point d.

d) The Z component is measure at right angles to the vector plane, which acts as its reference plane, hence:

e) The positive direction of Z typically being in an upward direction.

f) Z±Φdn is the Z component of the location of wheel n etc., measured at right angles to the vehicles vector plane.

g) Note that in some applications that Z±Φdn, may be substantially independent of the mode, and the vector datum point.

Hence in some applications, Z±Φdn may simple be written as Zn.

h) The reference point of wheel n in the vehicles vector plane is PVP ±Φdn, when the vehicle is in mode ±Φ and using vector datum point d.

Typically PVP±Φdn lies on a line at right angles to the vector plane, which passes through some reference point on the wheel, or its suspension, or on the wheel road contact area.

15) Another of the methods is to refer to the distance the vector plane is above a point on a wheel major axis as its suspension height Zsn, hence in this method:

Zsn the suspension height of wheel n, is the height that the vehicles vector plane is above, some wheel reference point, typically located on the major axis of wheel n.

16) Another of the methods, which may be of particular application, where a vehicle has a number of cruise modes etc., is to locate the position of the vehicles wheels, and or other components or accessories, on a system of polar co-ordinates where:

17) In one method two dimensional polar co-ordinates may be used to specify the location of a point which lies in the vehicles vector plane. Hence in this method the suspension height Zsn of wheel n, for example, may be used in addition to its two dimensional polar co-ordinates to locate wheel n, hence:

a) Rdn is the radius vector of the point PVP±Φdn in the vehicles vector plane, its origin (i.e., its pole), typically being located at the current vector datum point d.

b) θdn is the angular location of the point PVP±Φdn, in the vehicles vector plane. The reference for angular measurement, its polar axis, is typically coincident with the vehicles current major vector axis ±Φd.

c) Hence in this method the polar co-ordinates of point PVP ±Φdn in the vector plane, of wheel n, are Rdn, θ±Φdn where:

Rdn being the radius vector of point PVP±Φ on the vehicles vector plane, of wheel n, when the vehicle is using vector datum point d.

θ±Φdn being the angular location of point PVP±Φ on the vehicles vector plane, of wheel n, when the vehicle is in mode ±Φ and when the vehicle is using vector datum point d.

Zsn is the distance the vector plane is above the reference point on the major axis of wheel n.

PVP±Φdn is the location in the vehicles vector plane of wheel n, when the vehicle is in cruise mode ±Φ, and is using vector datum point d.

Typically PVP±Φdn lies on a line at right angles to the vector plane, which passes through some reference point on the wheel, or its suspension, or on the wheel road contact area.

18) In one form the location of the wheels, and or other components, may be specified by a system of three dimensional polar co-ordinates.

CRUISE MODE

In one form of the invention, the methods used, when the vehicle is in cruise mode include the following:

1) One of the methods used to calculate the angle of steer and RPM of each wheel etc, is to treat the movement of the vehicle, at any instant as travelling an arc of a circle.

2) Another of the methods is cause the wheels of the vehicle to be substantially parallel and at angle ±Φ to the vehicles major axis zero (MAZ), at the moment that its mode changes to cruise mode ±Φ.

3) Another of the methods is to use the angle ±Φ, and the current vector datum point d, at the moment that it changes to cruise mode, to specify the current minor vector axis ±Φd and the cruise mode ±Φd.

4) That a preferred location of the vector datum point, on a vehicle with four wheels all of which are steerable and which are arranged in a regular pattern, is mid way between the front wheels and the rear wheels.

5) That a preferred location of the vector datum point, particular with vehicles with a number of unsteered wheels, where the major axes of all these unsteered wheels lie substantially in a vertical plane at right angles to the major vector axis of the vehicle, is that the vector datum point be located at the intersection of that vertical plane and the major vector axis.

i.e., with a vehicle similar to a conventional four wheeled car with two rear unsteered wheels, where their, major axes lie significantly in a vertical plane at right angles to the major axis of the vehicle, then the vector datum point may be located at the intersection of that vertical plane, and the major axes of the vehicle.

6) That the distance of the centre of the circle, an arc of which this vehicle is travelling, from the vector datum point is referred to as Rc. Also that Rc is specified by, the angular displacement of the steering wheel from its rest position via an angular (or linear) displacement sensor attached to the steering wheel, and by the position of the mode control, referred to here as a cruise crab control (via a sensor attached to this control).

The output signals from these two sensors are fed to a computer in the vehicle referred to here as the Motion Control Computer on which the software, referred to here as the Vector Control Software runs, which among other things locates the centre of this circle according to the methods of the invention.

Hence Rc the distance of the centre of the circle, an arc of which this vehicle is travelling, from the vector datum point is some function of the angular displacement of the steering wheel, from its rest position.

i.e.,	Rc	=	F(σsw).
Where	σsw	=	The angular displacement of the steering wheel from its rest position.

7) Also when the angular displacement of the steering wheel from its rest position is zero, or substantially so, then Rc is assumed to be infinite, or substantially so. Hence the angle of steer, of all the wheels of the vehicle are set to zero, i.e., all the wheels on the vehicle are substantially parallel.

8) The method of the Vector Control Software, in specifying the angle of steer of each wheel, is that in the first instance, it forces each wheel to point in a direction which is tangential to a circle of radius equal to the distance of that wheel from the centre of the circle (referred to above) of which this vehicle is travelling an arc.

9) The method of the Vector Control Software, in specifying the RPM of each wheel is that in the first instance it forces each wheel to turn at a speed which is proportional to the distance of that wheel from the centre of the circle (referred to above) of which this vehicle is travelling an arc.

10) In one form of the invention, when in cruise mode the method used to calculate the distance Rc, of the centre of the circle (about which this vehicle is turning an arc) to the vector datum point may be calculated by a algorithm, the basic form of which is:

a)	Rc	=	Ssw x Kr cotan Kσ σsw
	where Rc	=	The radius of the circle.
b)	Ssw	=	The sign of the angular displacement of the steering wheel from its rest position ±Φ. Note: Ssw = 1 for counter clockwise angular displacement Note: Ssw = -1 for clockwise angular displacement.

Note that due to the sign of the angular displacement Ssw, the centre of the circle may be located on the RHS of the vehicle for a clockwise angular displacement of the steering wheel, and on the LHS of the vehicle for a counter clockwise angular displacement.

Note that when σsw is zero or very small, then the radius Rc is assumed infinite, hence all of the wheels are parallel.

c)	Kr	=	The radius constant, or function. Refer to the following preferred values.

d) A preferred value of Kr when the vehicle has four wheels in a regular arrangement is:

$$Kr = WB$$

Where WB = the wheel base of the vehicle.

e) A preferred value of Kr when the vehicle has four wheels in a regular arrangement, with two steerable and two wheels fixed is:

$$Kr = \frac{WB}{2}$$

f) A preferred value of Kr for vehicles with an irregular, or otherwise, arrangement of wheel all of which are steerable is:

$$Kr = \frac{2\,(X\pm\Phi d_1 + X\pm\Phi d_2 + \quad + \quad + X\pm\Phi d_N)}{N}$$

g) A preferred value of Kr for vehicles with an irregular or otherwise, arrangement of wheels, all of which are steerable is:

$$Kr = R_{avd}$$

Where R_{avd} = The average radius of the wheels from the vector datum point d.

$$\text{i.e., } R_{avd} = \frac{R_{d1} + R_{d2} \ + \quad + Rdn + \quad + RdN}{N}$$

Where Rdn = $\sqrt{X\pm\Phi dn^2 + Y\pm\Phi dn^2}$

= The distance of Reference point PVPdn of wheel n from the vector datum point d. More specifically one preferred form of $K\sigma$, is to express it using an algorithm of basic form:

$$Kr = \frac{\sigma 90sw}{90}$$

Where $\sigma 90sw$ = The angular rotation of the steering wheel in degrees, to take the radius of the circle (of which this vehicle is turning an arc) from infinity (i.e., straight ahead) to zero (i.e., spin on the spot).
Note this method may still be used, even when the VWM's or other wheel assemblies, are not capable of sufficient angles of steer, such as to allow the spin on a spot mode.

PVP±Φdn is the location in the vehicles vector plane of wheel n, when the vehicle is in cruise mode ±Φ, and is using vector datum point d.

Typically PVP±Φdn lies on a line at right angles to the vector plane, which passes through some reference point on the wheel, or its suspension, or on the wheel road contact area.

h) N = The number of wheels on the vehicle.

i) $K\sigma$ = The angular constant (or function) of the steering wheel and its angular displacement sensor, and any gears etc, interposed between the steering wheel and its sensor.

One preferred format $K\sigma$, is to express it using an algorithm of basic form:

$$K\sigma = \frac{\sigma aosw}{90}$$

where $\sigma aosw$ The angular rotation of the steering wheel in degrees, to take the radius of the circle (of which this vehicle is turning an arc) from infinity (i.e., straight ahead) to zero (i.e., spin on the spot.
Note, this method may still be used, even when the VWM's or other wheel assemblies, are not capable of sufficient angles of steer, such as to allow the spin on a spot mode.

j) σsw = The angular displacement of the steering wheel from its rest position ±Φd.

11) In one form of the invention, a look up table or similar means, may be used which contains pre-calculated or experimental or other values in it, such that values for Rc similar to those obtained from the above algorithm may be obtained.

12) In one form when all of the wheels are steerable there may be any number of these cruise mode ±Φ's, also that the method of the invention typically uses the crab mode as an intermediate mode to allow it to change between these cruise mode ±Φ's, i.e., say between cruise mode $\pm\Phi_1$ and cruise mode $\pm\Phi_2$.

13) In one form of this invention, it is in the first instance the angular displacement of the vehicles wheels from the vehicles major axis, at the instant that it enters a cruise mode ±Φ, which specifies the ±Φ of the cruise mode. Typically all of the vehicles wheels being substantially parallel as the vehicle enters the cruise mode.

In one form of the invention, the number of cruise modes ±Φ, may be restricted to one, i.e., to cruise mode 0°.

In one form of the invention, the number of cruise mode ±Φ may be restricted to cruise mode 0°, cruise mode Φs and cruise mode -Φs, where Φs is some angle smaller than 90°.

In another form of the invention the number of cruise mode ±Φ's may be restricted to cruise mode 0°, cruise mode 90° and cruise mode -90°.

In another form of the invention, the number of cruise mode ±Φ's, may be restricted to some smaller or larger number of modes, and to some smaller or large values of Φ.

14) In one form of the invention, during the design or commissioning phases, computers (using basic trigonometric relationships) or otherwise may be used to calculate the co-ordinates of each of the wheels, relative to the major and minor vector axis of each of the allowable cruise modes. These co-ordinates are referred to here as X±Φdn and Y±Φdn, which are the co-ordinates of VPLdn, i.e., the reference point in the vector plane of wheel n, when the vehicle is using vector datum point d.

Hence a tables may be stored in non-volatile memory, or by other means, of the values of VPL±Φdn of all of the wheels, in all of the cruise modes ±Φ, for all of the vector datum points d.

15) In one form of the invention this table is used as a look up table by the Motion Control Software.

16) In one form, PVP±Φdn is located on the vehicles vector plane, by a line referred to here as the wheel contact line (WCL).

The wheel contact line (WCL) of wheel n, is a line at right angles to the vector plane and passes through the center of the wheel road contact area.

17) In one form similar to above, but where PVP±Φdn may be for example a significant function of the height of the wheels suspension.

In this form a common table may be produced which specifies the location PVP±Φdn for various suspension heights.

In this form the VCS or other software may apply a correction for any wheel using this common table.

18) In another form similar to above, tables of PVP±Φdn may be provided, for all of the wheels, each over a wide range of suspension height, with the corrections already made.

19) One form of invention may use sensors, both linear and angular, to provide data to the Vector Control software such that it may calculate (using basic trigonometric relationships, etc.) the co-ordinates of each wheel, on a instant by instant basis.

20) In one form of the invention, when in cruise mode, the method as follows may be used by the Motion Control Software, in calculating the RPM command which is sent to each wheel, i.e. RPM_1, RPM_2 .... RPM_N.

This may be performed by the Vector Control Software using an algorithm, the basic form of which is:

$$RPM_{\pm\Phi dn} = \frac{FR \times K_{RPM} \times (Am - FBRKm) \times Rw_{\pm\Phi dn}}{Rr}$$

Where:

$RPM_{\pm\Phi dn}$	=	The RPM command to wheel n, when in cruise mode $\pm\Phi dn$ and using vector datum point d.
Rr	=	Rc if Rc > = Ravd
Rr	=	Rav if Ravd >= Rc
FR	=	1 when the vehicle is travelling forward
	=	- 1 when the vehicle is travelling in reverse
K_{RPM}	=	The vehicles RPM constant.
	=	The RPM of the vehicles wheels when it is travelling in a straight line (i.e., Rc = infinity) at top speed (i.e., Acc = 1).
K_{RPM}	=	$\frac{1\,000\ Vmax}{120\pi\ Rewr} = \frac{2.653\ Vmax}{Rewr}$
Vmax	=	Vehicles maximum speed in km/hr.
Rewr	=	The effective wheel radius in meters.
Am	=	Am if Am >= K_{idle}
Am	=	K_{idle} if K_{idle} > Am
K_{idle}	=	The idle constant, note its range of values includes zero
Am	=	The Accelerators Modified Primary Signal (MPS) from the accelerators displacement sensor, after passing

through its Primary Modification Module (PMM).

Note: that when the signal from the accelerators sensor does not pass via a Primary Modification Module (PMM) then:

Am = Acc = The position of the accelerator

Note: Acc = 0, when at its rest position

Acc = 1, when at its maximum displacement

$FBRK_m$ = The Modified Primary Signal (MPS) from the force sensor on the brake pedal, after passing through its Primary Modification Module (PMM).

Note: that when the signal from the brakes sensor does not pass via a Primary Modification Module (PMM) then:

$FBRK_m$ = FBRK = The normalised force on the brake pedal.

i.e. FBRK = 0 if there is no force being exerted on the brake.

and = 1 if there is some "maximum" force being exerted on the brake.

Ravd is typically a constant, which acts to control the wheels RPM as Rc approaches zero, ie., spin on a spot mode (SOS).

A preferred value of Ravd is the average distance of the wheels from the vector datum point of the vehicle.

ie.,

$$Ravd = \frac{Rd_1 + Rd_2 + \quad + \quad Rdn + \quad + \ Rd_N}{N}$$

where

$$Rdn = \sqrt{X\pm^2\Phi dn + Y\pm^2\Phi dn}$$

Where N = The number of wheels on the vehicle.

where FR = The state of the Forward / Reverse Control

Note: FR = 1 in the forward position

FR = -1 in the reverse position.

Rc = the distance of the centre of the circle (about which this vehicle is turning an arc) from the vector datum point. Note: Rc was calculated earlier.

Kidle = A value from 0 to 1.0 which may set the speed of the vehicle when the accelerator is at its rest position etc.

$X_{\pm\Phi dn}$ = The X co-ordinator of wheel n in mode ±Φ, using vector datum point d.

$Y_{\pm\Phi dn}$ = The Y co-ordinator of wheel n in mode ±Φ, using vector datum point d..

a) When using Cartesian co-ordinates X±Φdn, Y±Φdn that Rw±Φdn may be calculated:

$$R_{w\pm\Phi dn} = \sqrt{X_{\pm\Phi dn}^2 + (Rc - Y_{\pm\Phi dn})^2}$$

= The radius of point PVPdn of wheel n, from the current CCA of the vehicle, when it is in cruise mode ±Φ and using vector datum point d. Note that CCA is the centre of the circle, of which this vehicle is turning an arc.

where $X_{\pm\Phi dn}$ = The X component of the location of PVPdn of wheel n, when in cruise mode ±Φ and when using vector datum point d.

I.e., $X_{\pm\Phi dn}$ is measured along the major vector axis ±Φ, from the current vector datum point d.

$Y_{\pm\Phi dn}$ = The Y component of the location of PVPdn of wheel n, when in cruise mode ±Φ, and using vector datum point d.

I.e., $Y_{\pm\Phi dn}$ is measured along the minor vector axis ±Φ, from the current vector datum point d.

CCA = The center of the circle of which this vehicle is turning an arc.

b) When using polar co-ordinate Rdn, θ±Φd then Rw±Φdn may be calculated:

$R_{w\pm\Phi dn}$ = $\sqrt{(Rdn \cos\theta\pm\Phi dn)^2 + (Rc - Rdn\sin\theta\pm\Phi dn)^2}$
= The radius of point PVPdn of wheel n, from the current CCA of the vehicle, when it is in cruise mode $\pm\Phi$, and using vector datum point d.
Note that CCA is the centre of the circle, of which this vehicle is turning an arc.

R_{dn} = The vector radius of PVPdn of wheel n, when the vehicle is using vector datum point d. (Note that typically Rdn is independent of the cruise mode $\pm\Phi$).

$\theta_{\pm\Phi dn}$ = The angular location of PVPdn of wheel n, when the vehicle is in cruise mode $\pm\Phi$, and is using vector datum point d.

$\theta_{\pm\Phi dn}$ = $\theta\pm\Phi_{dn}$

21) In one form similar to the above, except the method is to use an algorithm for Rr of the following basic form:

Rr = $(Rc^p + R_{avd^p})^{1/p}$
where P = Some number, which may be 1.0 but, more typically will be 2 or 3 or higher.

22) In one form similar to the above forms, but in which the RPM of the wheels is caused to decrease as Rc falls below some value. The method is to use a value of Rr of the above basic form:

R_r = Rc if $Rc >= R_{SD}$
R_r = R_{SD} if $R_{SD} >= Rc$

Where R_{SD} = The "slow down" radius.
$R_{SD} = K_{SD} \times Rav$

when K_{SD} = 1 Then wheel RPM when in the SOS mode may be the same as the wheel RPM when the vehicle is travelling in a straight line.

when K_{SD} = 2 Then wheel RPM when in the SOS mode may be half of the wheel RPM when the vehicle is travelling in a straight line.

Etc Etc

i.e., the RPM of the wheel can be specified when Rc is small or zero, by the choice of K_{SD}.

23) In one form of the invention similar to the above except that the algorithm for Rr may be of the following basic form:

$$Rr = (Rc^p + Rsd^p)^{1/p}$$

24) In one form of the invention similar to the above, when in cruise mode 0°, and when the brake is not used, and when the signal from the accelerators sensor is not passed via a primary modification module and when the "slow down" feature is not required and when the vehicle has only one vector datum point. The method is to use an algorithm, the basic form of which are:

a) When using Cartesian co-ordinates:

$$RPMn = \frac{FR \times K_{RPM} \times Acc \times \sqrt{Xn^2 + (Rc - Yn)^2}}{Rc}$$

Where

RPMn = The RPM of wheel n.

Xn = The X co-ordinate of the location of PVPn of wheel n in the vehicles vector plane, measured along the vehicles major axis zero, from the vehicles vector datum point.

Yn = The Y co-ordinates of PVPn of wheel n in the vehicles vector plane, measured along the vehicles minor vector axis ninety, from the vehicles vector datum point.

Rc = The radius of the circle, an arc of which the vehicle is travelling

b) When using polar co-ordinates:

$$RPMn = \frac{FR \times KRPM \times Acc \times \sqrt{(RnCos\theta n)^2 + (Rc - RnSin\theta n)^2}}{Rc}$$

RPMn = The RPM of wheel n, when the CCA (center of the circle, an arc of which the vehicle is travelling) is at distance Rc, measured from the vehicles vector datum point along minor vector axis ninety.

Where Rn = Magnitude of the distance in the vector plane the point PVPn of wheel n, is from the vehicles vector datum point.

θn = The angular location, in the vector plane the point PVPn of wheel n is from the vehicles major axis zero.

Rc = The radius of the circle, an arc of which the vehicle is travelling.

25) In one form of the invention, when in cruise mode the method used by the Vector Control Software to calculate the angle of steer of each wheel is to use an algorithm, the basic form of which is:

a) Cartesian co-ordinates:

$$\phi\pm dn = SSW \times Tan^{-1}\left(\frac{X_{\pm\Phi dn}}{Rc - Y_{\pm\Phi dn}}\right)$$

Where

φ±Φdn = The angle of steer of wheel n measured counter clockwise from the current major vector axis ±Φd.

SSW = the sense of the current angular displacement of the steering wheel from its rest position RSW±Φ.
SSW = 1 when its counter clockwise i.e., to the "left"
SSW = -1 when its clockwise i.e. to the "right"

X±Φdn = the X co-ordinate of wheel n in cruise mode ±Φd using vector datum point d.

Y±Φdn = the Y co-ordinate of wheel n in cruise mode ±Φd using vector datum point d.

Rc = the radius of the circle, about which this vehicle is turning an arc as may be measured along the vehicles minor vector axis ±Φd. (Note, Rc is calculated earlier).

Additionally note from the above algorithm that when the steering wheel has been moved in a clockwise direction, that σn is also in a clockwise direction for wheels in front of the minor vector axis ±Φd, and anti-clockwise for wheels behind the minor vector axis ±Φd. Also that the angle of steer of wheels on the minor vector axis is fixed.

Also for a counter clockwise displacement of the steering wheel, the converse in the case.

b) When using polar co-ordinates:

$$\phi\pm dn = SSW \times Tan^{-1}\left(\frac{RnCos\theta n\pm\Phi d}{Rc - Sin\theta n\pm\Phi dn}\right)$$

Where $\phi\pm dn$ = The angle of steer of wheel n measured counter clockwise from the current major vector axis $\phi\pm d$.

SSW = the sense of the current angular displacement of the steering wheel from its rest position $RSW\pm\Phi$.
SSW = 1 when its counter clockwise i.e., to the "left"
SSW = -1 when its clockwise i.e. to the "right"

26) DELETED

ROADS WITH CAMBER

27) Most roads particularly those driven at speed, have camber.

(a) In one form of the invention, at any instant the (typically small) section of road surface being travelled is considered as lying in a plane (in some cases it may be horizontal) which is referred to here as the road surface plane (RSP). The angle between a line in the surface of the road, which is a radius of the circle, an arc of which the vehicle is travelling and the horizontal plane is referred to here as the angle of camber κ. Also note that this radius is referred to here as the radius of arc with camber κ (RAκ.).

(b) Consider a flat horizontal plane, and the road having an angle of camber κ. Here the road surface plane (RSP), of any typically small section of road, is at angle κ to the horizontal plane, when measured along RAκ. Note that the roads angle of camber κ may change, as you travel along the road, hence the angle of camber κ of one small section may vary from another small section.

(c) Positive camber ie., (+κ is used here to refer to the sense of the camber, and indicates that the camber may assist a vehicle to negotiate the arc. It also may indicated that the centre of this circle an arc of which this vehicle is travelling (CCA), may be beneath the vehicles vector plane.
Negative camber (-κ) is used to refer to the converse of this.

28) In one preferred form of the invention where the position of the steering wheel is being manually controlled by an operator, the method is to use an algorithm, as described previously, to calculate the radius Rc of the circle an arc of which vehicle is travelling, when the angle camber of that section of road is κ.

Hence the vehicles minor vector axis on which, the centre of the circle (CCA), an arc of which the vehicle is travelling, may be located, may be at angle κ to the horizontal plane.

Hence when a vehicle is being manually operated, on a road with camber, κ there is no change in the previous method of calculating the distance Rc of the centre of the circle, an arc of which the vehicle is travelling (CCA), from the vehicles vector datum point (VDP).

ie., Rcκ may still be calculated by an algorithm of the following basic form:

$$Rc \quad = \quad Ssw \times Kr \cot Kσ \; σ_{SW}$$

29) Consider a vehicle using the methods as discussed above, which was travelling in a straight line, and now enters an arc of the road with positive camber κ, then the operator will find (just as in a conventional vehicle under these same conditions) that the required displacement of the steering wheel, as it enters the arc, is reduced, compared with what it would be if an arc of road, similar to above, but with κ = 0 was entered.

Note that if Rco is the radius of a road with zero camber (ie., κ = 0), then Rco is referred to here as the effective radius of the arc of that section of road.

Also in the method of this invention that the effective radius of an arc of a section of road, with non-zero camber may be calculated by an algorithm of the following basic form:

$$Rco = \frac{Rc}{\cos κ}$$

30) In another preferred form of the invention similar to the above, but now the angle of roll of the vehicle may be measured.

Typically this form of the invention is applicable to vehicles with suspension height sensors, or other means of determining the angle of roll ρ (rho) of the vehicle.

One of the methods of this form of the invention is to define the angle of roll ρ as being the angle between the vehicles minor vector axis and the road surface plane (RSP). Also in this method that the angle of the vehicles minor vector axis β to a horizontal plane, may be expressed by an algorithm of the following basic form:

$$ρ = κ - β$$

β = The angle of the vehicles minor vector axis to a horizontal plane.

κ = The angle of camber of the (typically small) section of road the vehicle is on.

ρ = The angle of roll of the vehicle.

Also

$$β = κ - ρ$$

31) In one form of the invention similar to the above two forms, and which is of particular application, where the position of the steering wheel is being manually controlled by an operator. In this form no account may be taken of the angle of roll ρ of the vehicle, in the calculation of the radius Rc of the circle an arc of which the vehicle may be travelling.

i.e., Rc may still be calculated by an algorithm of the following basic form:

$$Rc \quad = \quad Ssw \times Kr \ \text{cotan} \ K\sigma^{\ \sigma sw}$$

32) In one form of the invention similar to the above, but now the effects of the vehicles roll may be taken into account when calculating the radius Rc of the circle an arc of which the vehicle is travelling.

The method is to locate an axis referred to here as the minor radial axis (MRA), one end of which passes through the vector datum point, and which is coincident with the vehicles minor vector axis when the angle of roll ρ of the vehicle is zero.

Also this minor radial axis (MRA) may lie in a plane, which is at right angles to the road surface plane, and in which the vehicles minor vector axis lies. Also this minor radial axis (MRA) may be at an angle β to a horizontal plane where:

$$\beta = \kappa - \rho$$

(as described previously)

Another of the methods of this form is to locate the centre of the circle (CCA), an arc of which the vehicle is travelling, on the minor radial axis (MRA), at a distance Rcβ from the vehicles vector datum point, given by an algorithm of the following basic form:

$$Rc\beta \quad = \quad Ssw \times \text{cotan} \ K\sigma^{\ \sigma sw}$$

ie., note that: Rcβ may equal Rc.

ie., in the first instance, taking the vehicles roll into account may not change the magnitude of the distance the CCA is from the vehicles vector datum point.

33) In one form of the invention similar to the above form, when the vehicle is travelling an arc of an circle on a road with camber κ, and the vehicles roll is ρ. And in this form the vehicles CCA may be located on the vehicles minor vector axis. The RPM of the wheels may be calculated by an algorithm, the basic form of which is:

$$RPM_{\pm\Phi dn} = \frac{FR \times K_{RPM} \times (Am - FBRKm) \times Rw_{\pm\Phi dn}}{Rr}$$

Hence this method is unchanged from the basic form. And in the first instance the only inaccuracy's are due to the location of the CCA on the vehicles minor vector axis (instead of on the vehicles minor radial axis (ie., this corresponds to not taking the vehicles roll ρ into account.

Note that in some applications the errors involved may be so small, such this form may still offer excellent performance.

34) In one form of the invention similar to the above, but now the vehicle contains suspension height sensors, such that the angle of roll ρ, may be calculated, and here the method may be similar to above except that:

(a) The CCA may be located on the vehicle minor radial axis (instead of an the vehicles minor vector axis).

(b) The variation in wheel RPM will typically depend on the type of suspension.

CRAB MODE

1) In one form of the invention, the methods used, when the vehicle is in crab mode include the following:

2) The angle of steer of all wheels is forced to be the same, or substantially so. Hence when in crab mode all of the wheels are parallel or substantially so.

$$\text{Hence } \phi_n = \phi_1 = \phi_2 \text{ etc.} = \phi_N$$

In one form of the invention, when in crab mode, the angular displacement of each wheel, from the major vector axis, may be calculated with an algorithm of the following basic form:

$$\phi_n = K_C \times \sigma sw$$

Where K_C = The angular displacement constant (or function) of the angle of steer when in crab mode.

σsw = The angular displacement of the steering wheel, from its rest position.

3) Typically only vehicles in which all wheels are steerable, may be used in crab mode as described here.

4) Typically $Kc = K\sigma$.

Hence:

$$\phi_n = K\sigma \times \sigma sw$$

5) That the RPM of all wheels is the same

$$RPM_n = RPM_1 = RPM_2 = RPM_3 \text{ etc}$$

TRANSITION BETWEEN CRUISE AND CRAB MODES ETC

1) In one form of the invention, the methods used to change between the modes includes the following:

2) One method used when changing from cruise mode to crab mode, is to arrange all the wheels on the vehicle such that they are parallel before it exits the current cruise mode $\pm\Phi$ to enter crab mode.

Hence the angle of steer of all of the vehicles wheels may be at $\pm\Phi$ to the major axis zero of the vehicle, or substantially so.

3) Another method is that when the vehicle exits crab mode, that it is the value of $\pm\Phi$, i.e., the angle of all the wheels to the major axis zero of the vehicle when it exits crab mode, that define the cruise mode $\pm\Phi$ which it has entered.

4) Another method is to use crab mode, as an intermediate step, as the vehicle changes between various cruise modes $\pm\Phi$, ie., between cruise mode $\pm\Phi_1$ and cruise mode $\pm\Phi_2$.

ADDITIONAL STEERING AND CONTROL METHODS

1. Vehicles where the minor vector axis may move

In one form of the invention, of particular application to vehicles with their wheels arranged in a manner similar to that of conventional vehicles such as cars and trucks and off road vehicles etc.

a) When the vehicle is operating at slow speed, or under other conditions, it has a mode where all wheels are steerable, under the control of the vector control software. For example if the vehicle has four wheels, the minor vector axis may be located mid-way between the front and rear wheels. And the vector datum point is located at the intersection of the minor vector axes and the major vector axes.

b) When the vehicle is to operate under other conditions, i.e., when at speed or on a public road or under other conditions. Then the vehicle may lock the steering on the rear wheels, typically in their straight ahead position, i.e., 0° angle of steer using steering lock mechanisms as described in this invention, or by other means.

The locking of the steering mechanism on the rear wheels may be initiated by manual means, i.e., via an operator control referred to here as a Free/Fixed Control (FFC) or automatically, i.e., under the control of the Vector Control Software (VCS).

Where a manual Free/Fixed Control (FFC) is provided, it typically will be fitted with a sensor the output of which feeds to an input of the Motion Control Computer (MCC) so as to inform the VCS of the selected mode, i.e., free or fixed.

Where:	"Free"	refers to the mode where there is considerable degree of freedom in the steering due to all wheels being steerable, hence both cruise and crab modes may be available.
	"Fixed"	refers to the mode where the rear wheels have their steering mechanism locked, and hence

typically the vehicle may only be able to operate in cruise mode 0°.

c) When the Free/Fixed Control (FFC) is moved to its fixed position, or when the VCS automatically causes the vehicle to enter the fixed mode, then the steering mechanism on the rear wheels may be locked and the minor vector axis, and hence also the vector datum point, move to a new location.

Typically where there is only two rear wheels, and where these two wheels have their major axes substantially lying in a vertical plane which is at right angles to the major vector axis, then typically the minor vector axis will now be located also within this vertical plane, and the vector datum point will be located where the minor vector axis intersects with the major vector axis.

2. In one preferred form of the invention, when the vehicle is in cruise mode, similar to the above, but now the value of Kr changes when the two rear wheels have their angle of steer locked.

a) When all wheels are steerable

$$Kr = WB$$

b) When the two rear wheels are locked.

$$Kr = \frac{WB}{2}$$

ADDITIONAL METHODS USED IN THE CONTROL OF THE WHEELS RPM

1. Undulating or Rough Ground Surface

a) In one form of the invention, in the first instance, the RPM of each wheel is specified and held within close limits such as to provide optimum traction and a minimum amount of sliding should a patch of ice or oil etc be encountered on the road.

b) In one form of the invention similar to above, each Vector Wheel Module or wheel assembly includes in its status the height of the suspension in each Vector Wheel Module and or Vertical acceleration being experienced by that Vector Wheel Module. Here the Motion Control Software (in the Motion Control Computer) calculates how much each wheel is forced to go faster or slower as it passes through the undulations, such that now the RPM of each wheel is held within close limits of RPMun, the RPM of wheel n over the undulating surface.

c) In one form of the invention, similar to the above, it is the vector control software in the vector control computer in each vector wheel module etc., which calculates how much faster or slower it may force its wheel to turn, as the wheel passes through the undulations.

2. In one form of the invention with a suspension height sensor, the method used is of the following basic form:

a) At regular intervals of time (which typically will be small), the method calculates the RPM of each wheel, such that the component of the lineal velocity of a point on the wheel which lies in a plane parallel to the vector plane of the vehicle remains constant, or at least substantially so.

Let Δ T= the small time interval (which typically may be of the order of milliseconds or tens of milliseconds etc.

Let Δ DPn= the modulus of the distance travelled parallel to the vector plane of the vehicle in time ΔT, by wheel n.

i.e., Δ DPn= |Previous DPn – Current DPn|

i.e., in this form of the invention, in the first instance the lineal distance travelled by wheel n, in a plane parallel (or substantially so) to the vector plane of the vehicle, in time Δ T is referred to as ΔDPn.

b) During the interval of time ΔT the component of the wheel's movement at right angles to the vector plane of the vehicle is ΔHRn. Also at the end of time interval ΔT, the suspension height sensor is read, typically by the vector control computer (VCC) in wheel n, and saved in memory. Next, typically the VCC subtracts this reading from its previous reading of the height of the suspension (ie., ΔT earlier). The modulus of the different reading ΔHRn is also typically stored in memory in the VCC.

Δ HRn= |Previous HRn – Current HRn|

c) In this form of the invention the corrected RPM of wheel n is now calculated by an algorithm of basic form:

$$\text{RPMun} = \frac{\text{RPMsn}\ \sqrt{\Delta \text{DPn}^2 + \Delta\, \text{HRn}^2}}{\Delta \text{DPn}}$$

where:

RPMun	=	The corrected RPM of wheel n over the undulating surface.
RPMsn	=	The specified RPM of wheel n.
Δ DPn	=	The component of the distance travelled by wheel n, parallel to the vector plane of the vehicle in time ΔT.
ΔHRn	=	The component of the distance travelled by wheel n, at Right angles to the vector plane of the vehicle in the time ΔT.
ΔT	=	The small interval of time.

3. In one form of this invention similar to the above, but now, the status from each wheel, sent back to the vector control software, will include the height of the wheels suspension. In this form it is the vector control software which calculates RPMun, typically by a software Secondary Modification Module (SMM).

4. In one form of this invention, when the Vector Control Software (VCS) detects, via suspension height sensors or tilt sensors or vertical acceleration sensors in each vector wheel module, that the vehicle is on undulating or rough ground. In this form of the invention when the undulating ground etc is detected the VCS may automatically enter a mode of operation referred to as Equal Torque Mode (ETM).

Vehicles may use the equal torque mode as an alternative to the above two forms of the invention.

The equal torque mode (ETM) allows the RPM of each wheel to vary (within certain limits) from its primary (and secondary) value such as to allow the wheels to speed up, or slow down etc, as the vehicle travels through undulations.

ie., the ETM mode acts to make the drive to each wheel more "springy" (ie., the torsional rigidity is reduced) such that each wheel is able to increase or decrease its RPM (within limits) as the torque experienced by the wheel changes.

Typically the amount of deviation from the specified RPM will be controlled by the VCS such that the maximum torque capability of any of the polyphase traction motors is not exceeded. Details of the ETM mode are described elsewhere in this document. Generally however, the use of the ETM method, allows less tight control of the RPM of each wheel, and while it may be simple and low cost, it may not offer the most optimum solution over undulating ground, as for example the previous two form of the invention.

In another form of the invention similar to above, but the automatic entry and exit from the ETM mode is disabled. Instead a manual control is provided such that should the vehicle be on undulating ground the operator can operate the control and force the vehicle to enter the ETM mode, and similarly the operator can also force the vehicle to exit the ETM mode.

In a further form of the invention an additional operator control may be provided such that in one state the automatic entry and exit from the ETM is provided for, while in the other state the automatic entry and exit is disabled.

5. Equal Torque Mode (ETM)

One of the foundation principals of this invention is that in the first instance, that optimum traction etc is obtained by the powering of all wheels, and secondly by the forcing of each wheel to turn at a precise RPM as specified by the Motion Control Software, which calculates the precise RPM of each wheel according to the methods and algorithms as detailed in this invention.

However, under certain conditions, and or at certain times etc, it may be beneficial in terms of performance, or allow cost savings, or for other reasons to relax the precise control of each wheel RPM. A mode used to achieve this is referred to here as the Equal Torque Mode (ETM).

In one form of this invention a mode referred to as the Equal Torque Mode (ETM) is provided (typically as a ETM software module within the MCS) which controls the RPM's of the wheels such that in the first instance all operate with the same torque (or substantially so). An algorithm of the following basic form may be used:

a) Adjust the RPM of the wheels such that, the torque applied to each wheel is the substantially the same

i.e.,

$$Tqav = TQ_1 = TQ_2 = TQn = TQ_N$$

$$\text{where} \quad Tqav = \frac{TQ_1 + TQ_2 + \ldots\ldots\ldots TQ_N}{N}$$

The vehicle has N wheels
TQav = the average torque
TQn = the torque on wheel n.

b) Control the amount by which the RPM of any wheel is allowed to deviate from its specified value (typically again by the ETM software module within the MCS).

(i) The lowest allowable RPM may be expressed in terms of its Lowest Normalised RPM (LNR). This will typically occur when the wheel is being driven, i.e., when the polyphase traction motor is acting as a motor.

$$\text{i.e., } LNRn = \frac{RPMan}{RPMsn} >= LNR$$

Where
LNRn = The lowest normalised RPM of wheel n.
RPMan = The actual RPM of wheel n.
RPMsn = The specified RPM of wheel n.
LNR = The lowest allowable normalised RPM. Note, that typically LNR may be in the range of 0.8 to 1.0.

(ii) similarly its highest allowable RPM may be expressed in terms of its highest normalised RPM (HNR). This will typically occur when the wheel is braking, i.e., when the wheels polyphase traction motor is acting as an alternator.

Also in this form of the invention, when a wheel is being driven then its

$$HNR_n = \frac{RPMan}{RPMsn} <= HNR$$

where	HNRn	=	Highest normalised allowable RPM of wheel n
	HNR	=	the highest normalised RPM. Note, that typically HNR may be in the range 1.0 to 1.25.

(iii) Also in this form of the invention typically:

$$LNR_n \times HNR_n = 1$$

6. In another form of the invention similar to the above if the RPM of any wheel is at, or exceeds, its maximum allowed deviation then its torque is not included in the calculation ie., this wheel is assumed to be spinning or slipping etc, and is disregarded.

i.e.	if	RPMan	=>	HNRn x RPM_{sn}
or	if	RPMan	=<	LNRn x RPM_{sn}

Then its torque is disregarded in the calculation of the average torque TQav. Also it is struck out of N, ie., the count would now be N-1.

7. General Note on the Equal Torque Mode (ETM)

Consider a vehicle travelling in a straight line with its ETM mode enabled then typically the wheels may turn at different RPM's. For example, if a maximum normalised deviation was specified by the MCS or by other means at 0.9 to 1.1, and if the primary RPM as set by for example the displacement of a sensor attached to the accelerator was 150 RPM. Then typically the RPM of any wheel could vary between 135 RPM and 165 RPM, provided the vehicle is travelling in a straight line.

Consider for example now the case of a vehicle which for simplicity has its four wheels arranged like a conventional vehicle (ie., basically all four wheels are the same distance from the major axis of the vehicle). And further lets assume that this vehicle is turning through an arc of a circle such that the specified RPM of the "outer" wheels is twice the specified RPM of the "inner" wheels, and also that the primary RPM setting of the sensor on the accelerator still corresponds to 150 RPM.

Hence RPM outer = 2 x RPM inner.

$$\text{also} \quad \frac{\text{RPM outer} + \text{RPM inner}}{2} = \text{RPM prim}$$

$$\therefore \quad \text{RPM outer} + \text{RPM inner} = 300$$

$$\therefore \quad 3 \times \text{RPM inner} = 300$$

$$\therefore \quad \text{RPM inner} = 100\ \text{RPM}$$
$$\text{And} \quad \text{RPM outer} = 200\ \text{RPM}$$

And assuming that the maximum Normalised deviation limits of the wheels RPM are still set at 0.9 to 1.1. Hence the actual RPM of the "inner" wheels could be any where in the range 90 to 110 RPM. While the actual RPM of the "outer" wheels could be anywhere in the range 180 to 220 RPM.

8. Wheel Radius Profile (WRP)

Consider the effect of wheels of different radius on a vehicle controlled by the Motion Control Software. As described earlier the Motion Control Software has the ability to control the RPM of each wheel to within a few percent or better. Yet the radius of commercially available tyres may vary by more than this, also if the vehicle happens to be loaded more on one side than the other, the effective radius may vary even more. This could cause uneven loading of the tractive force being exerted by various wheels, and hence their polyphase traction motors.

In one form of the invention the vector control software may include a feature referred to here as Wheel Radius Profile, which contains details for the ratio's of the effective radius of each of the wheels on the vehicle. This profile is typically updated at regular intervals, or as may be otherwise specified. With vehicles capable of moderate or high speeds, the Wheel Radius Profile may contain values of the ratio's of the effective wheel radius at various speeds. The Motion Control Software builds this profile by waiting till the vehicle is travelling on, say, a flat smooth surface as may be indicated by a tilt angle sensor which feed the Motion Control Computer, and/or by accelerometers and or the suspension height sensors typically located in each of the Vector Wheel Modules (or other wheel assemblies). Once appropriate conditions are detected by the Motion Control Software, it uses the Equal Torque Mode (ETM) as it adjusts the relative RPM commands to each of the wheels till all of the traction motors are exerting the same torque or that all are within some tolerance. The ratios of the RPM's are calculated and stored typically in non-volatile memory in a format referred to here as the corrected Normalised RPM (CNR), and it is these CNR's that constitute the Wheel Radius Profile at these conditions. Some vehicles which do not have their traction motors fitted with strain gauges or other torque sensors, may instead use current sensors, which monitor the current drawn by each of the polyphase traction motors and the value of the current is used to calculate the torque being exerted by that wheel or by simply adjusting the RPM's of each of the wheels until the currents drawn by each polyphase traction motor is the same (or at least within some specified tolerance). Again, when conditions are as required by the Motion Control Software, it records the Corrected Normalised RPM's of the wheels. And again it is these CNR's which constitute the wheel radius profile.

In one form of the invention, when a vehicle is started after being stationary for an extended time, or for other reasons the Motion Control Software decides that the Wheel Radius Profile may not be accurate, it can again use the equal torque mode (ETM) to drive the polyphase traction motors.

Also the Motion Control Software may limit the top speed of the vehicle, till it has updated the Wheel Radius Profile, which could take a few seconds or minutes or longer of driving. Should this occur the Motion Control Software may display a warning on the control console etc., and indicate or otherwise that low speeds should be used.

9. In one form of the invention the corrected Normalised RPM's (CNR's) of the wheel radius profile are calculated by the Motion Control Software using a method, the basic form of which is:-

a) Wait till the vehicle is travelling on a smooth surface in a straight line, or is within some specified tolerance, of these conditions.

b) Enter the ETM mode and adjust the RPM of all the wheels till the Torque applied to all wheels is the same, or is within some specified tolerance.

c) Calculate the Correct Normalised RPM (CNR) of each wheel.

ie $$CNRn = \frac{RRMan}{RPMbsn}$$

where CNRn = the corrected Normalised RPM of wheel n

RPMan = the actual RPM of wheel n, at the end of the above processes, typically as measured by the RPM sensor associated with each wheel and sent as status to the MCS at regular intervals. (Also note that typically at the end of this process that RPMan will be the same as RPMsn – the specified RMP of wheel n).

RPMbsn = the basic specified RPM of wheel n, if the WRP is not taken into account.

In another form of the invention similar to the above, allows the calculation of the CNR's when the vehicle is travelling around and arc of a circle. The method is to use Step b and c as above. The basic specified RPM of wheel n (RPMbsn) is calculated by the MCS from the Primary RPM (RPMp) using the methods detailed elsewhere in this patent. This allows the calculation of the corrected normalised RPM (CNR), of the wheels of the vehicle as it is travelling around an arc of a circle.

10. In one form of the invention, similar to the above two forms the method and algorithms may be of the following basic form:

A) As Above.

B) The MCS enters the ETM mode and adjusts the RPM of all the wheel still the torque applied to all wheels is with some specified tolerance., ie.,

Ba) The MCS outputs the specified RPM commands RPM_1, RPM_2, ... RPM_N to all of the wheels, using the current WRP data.

Bb) The MCS will wait some period of time (which typically may be hundreds of milliseconds or even seconds) such that the wheels can reach the RPM's as specified.

Bc) The MCS will now read the torque being experienced by the polyphase traction motor driving each wheel (via the status information sent back to the MCS, typically at regular intervals.

Bd) Calculate the average torque.

$$\text{Ie., } TQav = \frac{TQ_1 + TQ_2 + \quad + \quad + TQ_N}{N}$$

Be) Check to see if each of the torques are within some specified value of TQav..

$$\begin{array}{l} \text{ie, } TQav + TQT > TQ_1 > TQav - TQT\ ? \\ TQav + TQT > TQ_2 > TQav - TQT\ ? \\ \text{etc} \quad \text{etc} \quad \text{etc} \quad \text{etc} \quad \text{etc} \\ TQav + TQT > TQN > TQav - TQT\ ? \end{array}$$

(where: TQT is the allowed torque tolerance)

(i) If above is true., ie., all torques are within tolerance then proceed to C below.

(ii) If above is not true, proceed to Bf below.

Bf) Calculate the deviation of wheel n's torque ΔTQn from the average TQav.

Bg) Calculate the new RPM for wheel n.

$$\text{NEW RPMn} = \frac{TQav \times \text{OLD RPMn}}{TQav + KTQ \times \Delta TQn}$$

Where	NEW RPMn	=	The new RPM command sent to wheel n.
	OLD RPMn	=	The old (previous) RPM command sent to wheel n.
	KTQ	=	The torque constant or variable. Note that typically KTQ may be less than 1.0.
	ΔTQn	=	$TQav - TQn$

(ii) Output the NEW RPMn command to wheel n.

(iii) Have the specified RPMs of all of the wheels been adjusted?
If no, proceed to Bf above.
If yes, proceed to Ba above.

C) Calculate the correct normalised RPM (CNR) of each wheel.

$$\text{ie., } CNRn = \frac{RPM_{an}}{RPMbsn}$$

Where:

CNRn	=	The Corrected Nomarlised RPM of wheel .
RPM_{an}	=	The actual RPM of wheel n, at the end of the above process, typically as measured by the RPM sensor associated with each wheel, and sent as status to the MCS at regular intervals. (Also note that typically at the end of the above, RPM_{an} will be the same as RPM_{sn} - the specified RPM of wheel n).
RPMbsn	=	The basic specified RPM of wheel n, if the WRP is not taken into account.

GENERAL ASPECTS OF THE OPERATORS INTERACTION WITH THE STEERING WHEEL, INCLUDING TACTILE FEEDBACK

1. General operation of steering

a) As described above, typically in the first instance, the operator displaces the steering wheel from its rest position by σsw.

b) Sensors attached to the steering wheel provide the signal σsw to the Motion Control Software (MCS).

c) The Motion Control software (MCS) output command ϕsn to each wheel n, such as to command its steering motors (linear actuators etc.) to turn their wheel to angle of steer ϕsn.

Note that ϕsn is typically calculated by the MCS according to the methods as described earlier.

d) Typically the above occurs on a real time basis, i.e., instant by instant a new command may be output from the MCS, such that the operation of the steering may appear smooth and responsive to the operator.

2. Restrained or locked wheel torque, TQ_{LKD}

In one form of the invention, the steering motors in the VWM's etc have a means of measuring the torque being applied by these motors as they steer the wheel, and include this in the status which is sent back to the motion control software. Hence this status may be used to provide signals to the steering simulation motor, such as to provide a torque component TQ_{LKD} One particular use of this is

to allow the operator to sense the torque being exerted by the steering motors when for example the vehicle is stationary etc where the steering of the wheels may be restrained or locked.

In this form the method may include the use of an algorithm of basic form:

	TQ_{LKD}	=	$- S_{sw} \times TQm$
Where	TQm	>=	(TQ_1 or TQ_2 etc TQ_n).
Ie.,	TQm	=	The maximum steering torque being exerted by any of the vehicles steering motors.

3. Slow down torque (TQ_{SD})

a) In one form of the invention when the MCS receives back the actual angle of steer from each wheel (ϕan), should it be outside some specified tolerance of ϕsn, and or otherwise indicate, that one or more of the wheels is unable to keep up with the rate at which the MCS in requiring the angle of steer of the wheels to be changed, then the MCS may output commands to the steering wheel simulation motor, to apply torque TQ Slow Down (TQ_{SD}), via the steering wheel to the operator to such as to tend to resist the operator turning it at such a rate.

This torque may appear as a viscous drag, or damping, to the operator.

Additionally a display or audible tone, or spoken word etc. may indicate that the operator should slow down the rate at which they are moving the steering wheel.

b) In one implementation similar to the above, a transducer (piezo ceramic, solenoidal, or voice coil etc.) is attached to or mounted inside the steering wheel. Should any conditions occur as described above, a voltage and or current waveform may be applied to the transducer under the control of the Motion Control Software. This will generate a vibration or shock wave in the steering wheel hence providing tactile feedback to the operator.

c) In one implementation some combination of the features of the above two forms may be provided.

4. In one form of the invention, the method used to apply tactile feedback to the operator via the steering wheel may use (or include) an accelerometer, referred to here as "accelerometer Y". Preferably accelerometer Y will be a wide bandwidth type with a response from zero frequency (i.e., DC) to ten or some tens of Herz and preferably one hundred hertz or more, and preferably also of solid state construction. Accelerometer Y may be mounted such that its axis is substantially parallel to the vehicles minor vector axis (i.e., its Y axis).

The method used may include an algorithm the basic form of which may be:

$$TQ_R = -Ssw \times K_{TQR} \times m \times ay$$

= The torque (or component of torque) applied to the operator via the steering wheel as specified using an accelerometer on the vehicles Y axis.

SSW	=	Sign of the steering wheel
	=	1 when the displacement is zero or CCW.
	=	- 1 when the displacement is CW.
K_{TQR}	=	The torque constant (or function) for the steering wheel, when using an accelerometer on the Y axis.
m	=	Typically the vehicles mass including all occupants and load etc.
ay	=	The vehicles acceleration along its Y axis as measured by an accelerometer Y, as described above.

In this from of the invention:

a) This torque may be applied to the steering wheel by a steering wheel simulation motor as described elsewhere in this invention.

b) The output signal from Accelerometer Y and its electronic and other means, may be of analogue from, and may be applied to an analogue input of the Motion Control Computer (MCC) to other computer means.

Alternatively the output of accelerometer Y or its electronic and other means may be of digital form, and applied to a digital input port of the MCC, or other computer means.

c) A software module referred to as the "Radial Software:, within the MCC or other computer means may process the signal from the accelerometer Y, according to an algorithm of the above basic form, and output a signal or signals to electronic or other means such as to control the steering simulation motor, such as to apply the torque (or torque component) TQ_R to the steering wheel and hence to the operator.

d) The constant (or function) K_{QTR} may be specified in the "radial software" or elsewhere.

Alternatively it may be some function of an operator (or maintenance staff) accessible control such as a switch or potential meter or computer and software means such as to allow the amount of the tactile feedback to be adjusted or specified.

e) In one implementation the numeric value used for the mass m may be some nominal number, i.e., say its unloaded mass plus the mass of say some average load. This implementation may be particularly relevant, where for example as discussed above, an operator control may be provided for K_{TQR}, the torque constant (or variable).

5. In one implementation, the mass m of the vehicle may be specified as a constant or function in the Radial software or elsewhere. Alternatively it may be specified by some operator accessible or other control.

Alternatively where the VWM's or other wheel assemblies have a suspension height or similar sensor, which may provide details of the degree of compression of some suspension element such as spring etc. Also where the displacement versus force (or weight) characteristic is know of these

suspension elements then the SWAY software may calculate the mass according to an algorithm of the following basic form:

(i) Wait till the vehicle is stationary or travelling in a straight line or some other condition.

(ii) The SWAY or other software is provided with the suspension height of the vehicles wheels, typically via the MCS which receives status from the VWM's etc.

(iii) Calculate the mass

i.e. $m = N(K_m + F_{(hs)})$

= The vehicle mass.

Km = The "unsprung weight" of a VWM etc. Typically this may be specified at design or commissioning etc.

N = The number of VWM etc.

$F_{(hs)}$ = Some function which describes the relationship between the suspension height hs of a VWM etc., and the weight and hence mass carried by it. Typically it may consist of a look of tables etc. in non-volatile memory.

ADDITIONAL METHODS USED IN THE CONTROL OF THE VEHICLES

1. The angle of steer of each wheel

Each wheel may have a brushless dc (BLDC) motor to steer the wheel without requiring any gears or belts and pulleys etc between the motor and the wheel pivot assembly.

Multiple BLDC steering motors may be used which can be stacked axially one on top of each other, along the axis of steer. BLDC motors of various diameters may be used, such that they can be located radially.

The Vector Control Software may control the angle at which each wheel steers, via its steering motor (or other means) such that in the first instance each wheel of a vehicle in cruise mode, is forced to point in a direction which is tangential to a circle of radius equal to the distance of that wheel from the center of the circle of which this vehicle is travelling an arc at that instant.

Additionally note that instant by instant the operator may change the position of the steering wheel, hence instant by instant the vehicle may be travelling an arc of a different circle.

Also the steering wheel may be fitted with an angular displacement sensor, which will typically be read by the motion control software at a rate such that the size of any change in the position of the steering wheel between any two lots of steering angle status is small such that the steering control will appear smooth and responsive to the operator.

In one form of the invention, each wheel will typically have one or more sensors to determine the angle of steer, i.e., the direction in which each wheel is pointing. This information along with other

status may be passed to the Motion Control Software running in the Motion Control Computer in the vehicle on a real time basis, many times per second.

Typically, the wheels steering angle sensor and the software and other computer means within the vector wheel module (or other wheel assembly) forms a feedback loop that allows the vector wheel module (or other wheel assembly) to achieve the desired steering accuracy.

Additionally the actual angle of steer of each wheel on the vehicle along with other status is sent to the Motion Control Computer running the Motion Control Software, many times per second from each of the Vector Wheel Modules (or other wheel assembly).

In one form the vector wheel modules (or other wheel assembly) may only be able to steer the wheel through some fraction of one revolution. Typically the angle of steer sensors used will be able to operate over a larger range of angles of steer.

In another form, the vector wheel modules may be able to steer through more then one revolution and in some cases multiple revolutions. However the angle of steer sensor may only need to indicate from 0° to 360°, due to the use of slip rings and other techniques to transmit power and data signals etc across the pivot mechanism.

In one form of the invention each vector wheel module (or other wheel assembly) will also contain a sensor or other means (i.e. strain gauge, etc) typically on which the steering motor , or linear actuator, mounts to measure the magnitude and sign (i.e. clockwise or counter clockwise) of the steering torque being applied to steer its wheel. Each vector wheel module (or other wheel assembly) will send details of the magnitude and direction of its steering torque along with other status information to the Motion Control Software, typically many times per second.

Note that typically this status may be used to indicate to the operator the torque being exerted by the steering motors, when the vehicle is stationary or travelling etc.

In one form of the invention, the operators steering wheel may have a sensor attached to it to measure the angular displacement of the operator's steering wheel. This data is sent to the Motion Control Software in the Motion Control Computer many times per second. In particular this data along with the position of the cruise / crab control is used to specify the radius of the circle, an arc of which the operator requires this vehicle to travel.

The steering wheel will typically turn through a greater angle than the VWM's or other wheel assemblies are steered through. Hence the angular displacement sensor on the steering wheel may need to operate over a greater number of revolutions, (or fractions of a revolution) than the steering angle sensors in the VWM's (or other wheel assembly), which measure the actual angular displacement of the wheels.

In one form of the invention tactile Feedback may be applied to the operators steering wheel by a steering simulation motor such that the system feels alive and responsive, so that the operator can judge the magnitude and sense of the steering torque being applied to the wheels, by the steering

motors, and also the magnitude and sense of the force which the surface of the road is exerting on the wheel.

2. Steering System Self Tests

In some forms of the invention, at power up, or at other times as may be specified by regulatory authorities etc the steering system may perform a comprehensive self-test on itself. The results of which may be displayed on the operators control panel and additionally may be stored in a flash or other non-volatile memory so as to provide a permanent record of the status of the steering system for use during maintenance and regulatory inspections etc.

In one form of the invention, a software module of the Motion Control Software running in the Motion Control Computer on the vehicle performs the steering system test. At the specified times (i.e. power on etc) the steering system test software may apply a command signal to the steering simulation motor and first check that the angular displacement sensor on the operators steering wheel sends back a signal indicating that the steering wheel has moved by the correct angular displacement. Additionally, the steering system test software may also check the status information from each of the vector wheel modules (or other wheels assemblies) to confirm that the wheel in each of these also moved by the correct amount or alternatively, if the vehicle is stationary (and the wheels are restrained by the road surface), that the torque developed by the steering motor was of the correct magnitude and sign.

In one form of the invention the steering system test similar to the above is fully automated and requires no operator intervention, additionally they may be initiated, and the degree of severity specified by maintenance and or regulatory personnel. Also typically each test may consist of a number of test cycles as described above. Also typically the test may be able to perform at a number of degrees of severity. I.e. the routine test typically being less severe, and more server tests being available for maintenance staff, and for example during annual or other checks by regulatory authorities, etc.

3. In one form of the invention the "play" in the steering system, and in particular in the gearbox or other power transmitive elements etc, used by the steering motors to steer the wheels may be measured and recorded. The steering simulation motor of this invention typically consists of a polyphase stepper motor or a Brushless DC Motor (BLDC) fitted with an angular displacement sensor. Now as the steering tests as described above are performed and each steering motor acts to turn its wheel. The difference between the, angular displacement of the steering motor, to move the wheel through a certain angle of steer $\phi 1$, and the angular displacement then required by the steering motor to return it to its original angle of steer $\phi 2$ is calculated by the steering test software module. Typically these results are displayed for the operator in addition to being stored permanently in flash or other non-volatile memory. The play is calculated by using an algorithm, the basic form of which is:-

$$\text{play} = |\phi 1| - |\phi 2|$$

Where $\phi\ 1$ = angular displacement of motor to turn to a particular position.

ϕ 2 = angular displacement of motor to return its original position.

4. In one form of the invention, when the steering motor has a sensor or other means of measuring the angular displacement of the motors shaft, the play and other characteristics, of the steering system may be tested by using an algorithm, the basic form of which is:

A) check that the vehicle is stationary, such that the wheels will need some appreciable torque to change their angle of steer.

i.e., is the vehicle speed = 0 ?

If no proceed to F.

If yes proceed to B.

B) record the angular displacement of each wheel, i.e., ϕown, and also the angular displacement of its steering motor θomn.

where ϕown = The initial or zero reading of the angular displacement of wheel n.

θomn = The initial or zero reading of the angular displacement of steering motor n.

C) Send a command to each wheel, such that it may cause a small angular displacement of the wheel in say, a clockwise direction. Then increase this command till the steering torque sensor, for each wheel indicates a specified test value of torque., i.e., TQ_{CWT}.

Ca) check that the sign of the torque, is correct, if wrong proceed to G.

Cb) record the angular displacement of wheel n = $\phi_1$wn.

Cc) record the angular displacement of steering motor n = $\theta_1$mn.

D) Send a command to each wheel, such that it may cause a small angular displacement of the wheel in the opposite direction to C. Increase this command till the steering torque sensor, for each wheel indicates a specified test value, i.e., - TQ_{CWT}.

Da) check that the sign of the torque is correct, if wrong, proceed to G.

Db) record the angular displacement of wheel n = $\phi_2$wn.

Dc) record the angular displacement of steering motor n = $\theta_2$mn.

E) Check the angle the wheel has steered through, if to large, fail this test.

ie., | ϕown. - $\phi_1$wn| >= ϕw max?
or | $\phi_2$wn. - $\phi_1$wn| >= ϕw max?
where θmax = some maximum specified displacement of each wheel during the test.

If either of the above is greater than σwmax, then proceed to G. Otherwise proceed to F.

F) Calculate the play in the steering system of wheel n as follows:

$$\phi_{PSmn} = (\theta_2 mn. - \theta_1 mn.) - K_{SR} (\phi_2 wn - \phi_1 wn)$$

Where:

$\phi_{PSmn\cdot}$	=	The angular play in the steering system of wheel n, referred to its steering motor.
K_{SR}	=	The ratio of the gear or other mechanism between the steering motor and the wheel. (Typically it may be larger than 1).

Also $\phi_{PSwn} = \dfrac{\phi_{PSmn}}{K_{SR}}$

= The angular play in the steering system of wheel n, referred to the wheel.

G) Test failed, record details, and indicate this to operator via warning indicator etc.

H) Test passed, record details.

5. In one form of the invention, similar to above but now a linear actuator, is used to steer the wheel.

Again a method similar to that detailed above may be used particularly when, the linear actuator consists of an electric motor driving a lead screw and nut arrangement (or similar).

In one form of the invention, similar to the above two forms, but now at least some of the items of the steering system, are duplicate, or triplicate, etc.

Again a method similar to the above two forms may be used, typically the test being performed for each of the duplicate or triplicate systems, etc.

In another form of the invention, a joystick is used as the operators steering control. All aspects of the steering operate in a near identical manner to that described above, the angular rotation of the operators steering wheel being replaced by the angular displacement in a left / right (i.e. sideways directions) of the joy stick, about its pivot point. Typically the vertical position of the joystick, being its rest or stationary positions and typically indicated to the operator by the tactile feedback due to a spring-loaded pin locating within a flat or depression at the top of the ball joint, which acts as the pivot point of the joystick.

6. Steering Override Mechanism (SOM)

The invention also describes an optional steering override mechanism, which may provide a back up steering system via a mechanical steering or other linkage to (at least some of the wheels) should the software controlled steering fail.

In one form it consists of mechanism which restricts the amount of freedom available, to the software controlled steering depending on the angle of steer. When the angle of steer is medium or high (such as when the vehicle is manoeuvring in rough terrain or a confined space), the degree of freedom provided by the SOM to the software controlled steering is also high. Similarly when the angle of steer is small, (as may occur during high speed driving on a motorway) the amount of freedom provided by the SOM is also small. Hence should the software controlled steering fail under such conditions, the steering override mechanism will provide a backup method of steering (via a mechanical linkage to the steering wheel) such that reasonably control of the steering is possible, and hence the risk of an accident is significantly reduced.

Hence, due to the characteristic as described above where the degree of freedom available to the software controlled steering system is some function of the angle of steer, this SOM may only causes minimal loss of the advantages of the computer controlled steering. Also, typically, the greatest errors in most mechanical steering linkages typically occur at medium to high angles of steer (which typically occur during low or medium speed driving). Additionally, when both systems are functioning correctly, the SOM and its mechanical steering linkage, or otherwise typically, play no part in the actual steering of the vehicle. Should a fault develop in the software controlled steering system, it is probable that the angle of steer of one or more of the wheels on the vehicle, will digress until it is restricted by the SOM which will prevent any further digression from the desired angle of steer, due to mechanical contact between two or more parts of the SOM. Typically one or more sensors may be provided in the SOM such that the status can be provided to the slave control computer, and the vector control software such that should the degree of freedom of one of the SOM's be reached, appropriate warning and other actions may be implemented. Typically it will inform the operator via a display etc as to which of the SOM's (or wheels) has developed a fault, and also that speed should be reduced and will typically remove power from the part of the software controlled steering mechanisms that failed, or take such action as to prevent or at least reduce the amount, which the software controlled steering mechanism can "fight" against the SOM and its mechanical, or otherwise, steering linkage.

In another form of the invention, the sensors in the SOM may provide status to the vector controlled software to indicate the amount of the freedom, that has been used on a instant by instant basis, such that a warning may be raised (at least in some cases) before the SOM acts to mechanically restrain the software controlled steering mechanism. Typically this form of the invention may include means of storing this status (the amount of the freedom used) in non-volatile memory such that it is available to maintenance and regulatory authorities etc.

In another form of the invention similar to the above some "torque multiplying mechanism" may be interposed between the steering wheel and the mechanical, or otherwise, linkage used to connect the steering wheel to the SOM, such as to enhance the operators ability to override the software controlled steering mechanism should it be necessary.

In one form of the invention similar to above the "torque multiplying mechanism" may make use of the steering simulation motor such as to apply additional torque via the mechanical steering linkage to the SOM so as to assist in the steering of the vehicle during such a fault condition as described above. A strain gauge or similar, may be interposed between the steering simulation motor and the mechanical, or other, linkage used to interconnect it to the SOM's.

The output status from the strain gauge or similar may be available to the vector control software such that it can cause the steering simulation motor to apply torque in the correct sense and appropriate magnitude such as to assist the operator in controlling the vehicle under fault or other conditions. Due to the steering simulation motor, being mounted on a stain gauge or by other method (i.e. the current drawn by the steering simulation motor, and the phase of the drive signals) the vector control software now has sufficient information to calculate the torque being applied to the mechanical steering linkage, and the torque being generated by the steering simulation motor. By subtracting the two (and observing the sign of both) it may calculate the torque that the operator is applying to the steering wheel. Hence if we consider the tactile feedback (torque) applied to the operator by the steering wheel just before a fault occurs, and then just after a fault has occurred (such as to require the active intervention of the SOM and the mechanical steering linkage), the vector control software may be able to control the steering simulation motor such as to cause minimum change or disruption in the tactile feedback to the operator via the steering wheel, even though typically the sign of the torque applied by the steering simulation motor, and its magnitude, may have changed.

In another form of the invention similar to above, a strain gauge or similar may be interposed between the steering simulation motor and the steering wheel. The magnitude and sign of the three torques may now be calculated i.e. the torque that the operator is experiencing as tactile feedback, the torque which the steering simulation motor is applying and the torque being applied to the mechanical steering linkage and hence the SOM's. The control of the steering simulation motor by the vector control software, (or other software), therefore effectively has a redundancy of status, and may in addition to controlling the torque such as to achieve the objectives of the previous form of the invention, also check that the sum of the three torques above (taking their sign into account) is equal to zero (or approximately so). Hence the vector control software may check instant by instant the integrity of the system.

Another form of the invention, is similar to above, but without a strain gauge (or other methods) of measuring the torque being applied by the steering simulation motor.

7. In one form of the invention the SOM's are fitted to all of the VWM's (or other wheels assemblies), and a mechanical steering linkage or other is provided from the steering wheel to each of the SOM's. Typically this will have one or more "sign change mechanisms" which will alter the sign (i.e. from a clockwise to counter clockwise and vice versa) of the steering effort being applied, via the mechanical steering linkage, to the VWM's (or other wheels assemblies) which are located behind the minor vector axis of the vehicle. Typically this "sign change mechanism" will require to change its sign, when the mode of operation changes from cruise to crab, and vice versa. The sign change mechanism may typically consist of gears and chains and sprockets and or belts and pulleys, or a pivoting arm, with a control such as an electric actuator to change the sign of the "sign change mechanism", under the control of the vector control software.

Another form of the invention is similar to the above, but may use one or more clutches (typically electrically operated) to control the sign of the sign change mechanisms again under the control of the vector control software.

Another form of the invention may not require any "sign change mechanisms", and particularly applicable to vehicles with a regular arrangement of VWM's (or other wheels assemblies) all of which may be fitted with SOM's. The mechanical linkages to the SOM's on the front two wheel can be of basic form. The mechanical linkages to the other SOM's (typically to the rear of the vehicles minor axis), are each typically fitted with a "engage / disengage mechanism", which is typically operated by electrical means such that the vector control software can engage or disengage these mechanisms. When "engaged" these mechanisms provide mechanical linkages between the steering wheel and the SOM's. When "disengaged" the mechanical steering linkages are disabled, such that those wheels have freedom to steer as controlled by the vector control software without restriction. Typically these "engage / disengage mechanisms" may consist of clutches (friction or "dog" type) or other mechanical means such as a pin which can stop two concentric, or adjacent, shafts from moving relative to each other. Typically these clutches or pin's etc may operated by electric means under the control of the vector control software. Typically these clutches or pins etc may have sensors associated with each, their output being available to the vector control software, such that the status of the clutches or pins etc can be verified. Typically vehicles of this form may restrict the modes of operation. This form of the invention may be used, for example by a vehicle which only uses cruise mode when it is travelling at speed.

In another form of the invention, similar to the above, and particularly applicable to vehicles with a regular arrangement of wheels, SOM's will be fitted to all of the wheels, but a mechanical steering linkage may only be provided to the two front wheels of the vehicle. The other wheels, may be provided with a steering lock mechanism typically consisting of electrically operated pin, bolt, tooth or band which engages with another mechanical arrangement such as to lock each of the wheels to a particular angle of steer (typically pointing straight ahead).

When operating at speeds below some specified value the rear wheel are unlocked so that full advantage can be taken of the software controlled steering. When the vehicles speed excess the specified value, the rear wheel steering locks may be actuated, such that these wheels are now locked. Typically sensors will be attached to the steering lock mechanism, such that their status can be checked by the vector control software to ensure that it is safe for the vehicle to travel at speeds exceeding some higher specified value, and typically the VCS will restrict he speed, should the sensors indicate that a wheel is not locked. Additional (or alternatively to the sensors described above) once the steering locks have been enabled, the vector control software may apply steering torque to those wheels and check that the angle of steer sensors do not change their position, hence confirming that these wheels steering has been locked securely.

In another form of the invention, similar to the above, except that now the SOM's are only fitted to the two front wheels, and not the rear wheels.

8. Algorithmic Mechanical Steer Mechanism (AMS)

In one form, the invention consists of a algorithmic mechanical steering mechanism (AMS) which, within certain limits, is capable of implementing the steering algorithm detailed elsewhere in this patent or other algorithms.

In this form of the invention the steering wheel may connect via a collapsible tube and gear box, etc., to the algorithmic mechanical steer mechanism (AMS) which may contain a cam of basic disk shape, the major axis of which may be vertical.

This cam may have a groove in the form of a spiral pattern, machined or otherwise, in it's top and lower surfaces. Typically, the spiral on each surface may be of the "opposite hand" when the cam is viewed from, say, the top (with x-ray eyes). When the cam is turned in, say, the "CW" direction when looking down from above, a cam follower (or similar) running in the spiral groove in the top side may move in the same direction as a cam follower (or similar) running in the spiral groove on the lower surface of the cam. Also note that the pitch of the spiral grooves will typically vary along the length of the spiral. Additionally, one or more guide mechanisms may be provided such that the two cam followers are, to a large extent, only able to move in a plane which typically may include the major axis of the cam. This plane typically may be at right angles to the major axis of the vehicle. Additionally, the cam followers are on opposite sides of the cam's major axis.

Hence, as the steering wheel is turned the two cam followers typically will both move in the same direction but due to the pitch of the spirals varying, that the distance between them typically may change in a controlled and calculated manner. The "tie rods" or other linkages between the can followers and, the steering arms on wheels on opposite sides of a vehicle may move such that the relationship between the angle of steer of the wheels and the angular displacement of the steering wheel may be as described elsewhere in this patent (i.e., cruise mode) or as otherwise specified. Also, the cam followers (or similar) described above may be of such construction as to allow them to run on

both sides of the groove which forms the spiral pattern. Typically, each cam follower may have two or more rollers or ball bearing assemblies on it. Such that these are able to rotate in opposite directions as the cam follower moves along its spiral groove. Alternatively, the cam follower may consist of, typically, two or more recirculating ball mechanisms such that two or more sides of the "cam follower" may be in rolling contact with the walls of a groove of basic spiral pattern machined into a surface of the cam. The basic shape of the cam typically may be that of a disk.

In another form of the invention similar to above but now with a cam which has the same sense spirals on both sides (when seen with x-ray eyes) and the pitch (of each spiral) versus the angular displacement of the cam maybe different. Also, now both of the cam followers are on the same side of the major axis of the cam.

9. In another form of the invention rather different to the above, a cam of cylindrical section is used. This time a groove, rather like a course thread is cut into the external cylindrical surface of the cam, the pitch of the groove changing from start to finish as per the preceding forms, such that a cam follower or similar (running in a guide, the major axis of may βρ is parallel to the major axis of the cam) is forced to move in the direction of the major axis of the cam, when the cam is rotated about its major axis (typically by a steering wheel, via right angle or otherwise gearbox).

In another form similar to above, two or more of the cams may be joined end to end, such that the major axes of all are in line. Each of these cams typically will be joined to each other such that when the steering wheel is turned, all of the cams turn in unison.

In this and the two preceding forms of this invention, the major axis of the cam may lie in a plane parallel to the surface on which the vehicle rests, and the major axis of the cam may be a right angles to the major axis of the vehicle. Also, when the steering wheel is turned all of the cam followers (or similar) may have the senses of the groove (or course thread) of the same sense, such that when the steering wheel is moved both of the cam followers move in the same direction but typically at a different rate. The relationship between the angle of rotation of the steering wheel and the position of each cam follower being specified typically by an algorithm of typically non-linear characteristics ie., again the pitch of the groove may vary along the length of each cam. Typically a different algorithm may be used for each cam.

METHODS USED TO CONTROL THE VEHICLES BRAKING

1. Braking

In the first instance, as detailed earlier, the Motion Control Software may control the vectoring in both speed and direction of each of the wheels within close limits (typically of the order of a few percent or better).

This accurate control of the wheels RPM at all times, i.e. during acceleration, travelling at constant velocity and in especially when the vehicle is braking. In particular, the control circuitry (under the overall control of the Motion Control Software) may change the magnitude of the torque

quickly (typically within a few tens of milliseconds, or a few hundreds of milliseconds), hence instant by instant, the RPM of each wheel may be held within close limits.

In one form of the invention the polyphase traction motor has the ability to change the direction of the torque applied to the wheel, i.e. the polyphase traction motor may during braking be regenerative action, momentarily, or otherwise, feed energy to the wheel, instead of extracting energy from the wheel and converting it to electrical energy.

As a result of above the actual RPM of the wheel may not deviate from the value specified in the command from the Motion Control Software for that instant by more than a small amount (typically a few percent or less). Hence as stated elsewhere in the first instance, each wheel is **forced** to turn at its correct RPM, irrespective of the road surface etc. Thus typically eliminating the possibility of a wheel locking or exhibiting other detrimental activity as may be experienced in a conventional vehicle, for example, on a wet or slippery road.

In one form of the invention where the Vector Wheel Module (or other wheel assemblies) may contain two or more braking mechanisms, the preferred braking method is regenerative braking, where a significant amount of the energy available during braking may be saved by storing it in energy storage devices, such as ultracapacitors and or batteries, etc.

Where all of the vector wheel modules or other wheel assemblies, and hence their wheels, are under the control of the Motion Control Software, the above may be equally true regardless of whether the vehicle is travelling in a straight line while braking, or going around a curve while braking. The speed of all of the wheels may be, instant by instant controlled within close limits as commanded by the Motion Control Software algorithm, as detailed elsewhere in this invention.

2. Forms of Braking

Typically one or more of the following four forms of braking may be provided: -

a) In one form of the invention, regenerative braking is the preferred mode which typically may cause the polyphase electric traction motors to become a source of electrical energy (instead of a sink) by reducing the RPM value in the speed command send to each VWM. Additionally, DC injection braking techniques, etc, may be used, under the control of the Vector Control Software.

The magnitude of the regenerative braking is typically available in the status from each of the VWM (or other wheels assemblies), it may be derived from the strain gauge or other sensors on which the polyphase traction motor mounts, or from the current sensor which monitors the current sunk or sourced by the polyphase invertor / Controller, and its associated polyphase traction motor.

b) In one form of the invention "current dump braking" is provided which consists of electronic circuitry and or computer means which, if it detects that a vehicle is decelerating due to regenerative braking at such a rate that the maximum charge rate of the battery (or its maximum voltage during charge, or the maximum voltage across a ultracapacitor, etc.) is about to be exceeded, the current dump circuitry is activated and dissipates the excess electrical energy in a resistor as heat. Typically the

resistor used to dissipate this heat may be on the outside of the VWM, or may be mounted such as to dissipate the heat to the air external to the VWM etc.

c) In one form of the invention, friction braking, using typically normal disc brake rotor and stator (callipers) are provided, where the kinetic energy of the vehicle is dissipated as heat. In this invention the stator (i.e. the callipers) of the friction brake assembly may be mounted on a strain gauge or other sensor so as to measure the magnitude of the braking torque due to friction braking.

d) In one form of the invention a pin or other mechanism typically electrically/electronically actuated is provided under the control of the vector control software such as to mechanically lock the wheel or it's polyphase traction motor, etc.

In the preferred form of the invention the friction brakes are only enabled at relatively low speeds or for example if the regenerative braking circuit fails etc such that the polyphase tractor motor is unable to develop the required braking torque.

ie., typically friction braking is only employed when the braking torque as indicated by when the output signal from the strain gauge or other sensor on which the polyphase traction motor mounts (or the magnitude of the regenerative braking current from the polyphase motor) falls below that, which would indicate the required braking torque.

In one form of the invention the friction brakes may be of conventional hydraulic operation. In one embodiment, a hydraulic pump (similar to a conventional master cylinder) is attached to the foot brake. The output from the master cylinder goes via hydraulic hose and or pipe to the stator (calliper) of the friction brake located on each wheel (or wheel assembly). A hydraulic pressure relief valve (electrically / electronically operated) is mounted on the hydraulic lines, and controlled by the vector control software such that it only closes, and hence applies pressure to the stator (calliper) of the friction brakes when the braking torque on one or more of the wheels (due to the regenerative braking) has been found to fall below the required level.

In a further embodiment of the friction braking system where the vehicle has an equal amount of regularly arranged wheels (similar to a conventional four or six wheel vehicle), a hydraulic pump (similar to a conventional master cylinder) may be provided for each pair of wheels. A vehicle with four wheels may have two hydraulic pumps attached to the foot brake. The pressure line out of each pair of wheels being fitted with a pressure release valve (electrically / electronically operated). The vector control software controls these such that it is closed when the braking torque on either of the pair of wheels is detected to have fallen below the required value.

In a further embodiment of the friction braking system, the vehicles' foot brake is connected via a hydraulic pump, one for each of the wheels on the vehicle. Now a electrically / electronically operated pressure relief valve is provided for each wheel on the vehicle. The relief valve is normally open, but closes when the braking force due to other means (i.e. Regenerative) is detected to have fallen below the required level.

All of the above implementations may have a hydraulic pump attached to the operators foot brake. A servo or other force-multiplying device may be positioned between the foot brake and the friction brake. This may be used to apply fluid under pressure to the friction brake mechanism located on the wheels.

3. Foot Brake

In one embodiment, the foot brake may output an electrical or electronic signal proportional to the force being applied to the foot brake. This signal may pass to an input of the Motion Control Computer on which the Motion Control Software runs or to the other computer means. A spring or springs may be used to return the pedal to its rest position when the operator's foot is removed. These will typically have a non-linear force versus length characteristic, such that as the foot brake nears its maximum depression, the force per unit displacement may be high compared with a low force per unit displacement when in its rest position. That is, the force per unit displacement characteristic may be some exponential or similar function, such that it will feel to the operator much like a foot brake on a conventional vehicle with hydraulic brakes etc. A strain gauge (or other sensor) being interposed between the spring and the chassis, or within the pedal, or otherwise such as to measure the magnitude of the force being exerted on the foot brake, by the operators foot.

A further embodiment of the brake control system consists of a pedal, spring, and force sensor (similar to the preceding section). Also included is an accelerometer (typically solid state) or other sensor mounted in the vehicle to measure the acceleration / deceleration of the vehicle along its preferred direction of travel (i.e. typically along the major vector axis of the vehicle). The accelerometer is referred to here as accelerometer X, because its axis may be coincident with the vehicle X axis. The output of the accelerometer is fed into the Motion Control Computer on which the vector control software runs. Additionally a velocity sensor may be used, such as a Doppler type using electromagnetic waves i.e. the beam of a laser, microwave or other radio frequencies, or acoustic waves including ultrasonic or higher frequencies, to measure the actual velocity of the vehicle over the ground. Hence the acceleration/deceleration can be calculated by software in the vehicle by calculating the change in velocity per unit time.

The system may consist of one or more accelerometers and or one or more velocity sensors or some mix of acceleration and velocity sensors such that the magnitude and sense of the acceleration/deceleration may be accurately determined, on a real time basis instant by instant, by the Motion Control Software in the Motion Control Computer, or by other computer means and this data supplied to the Motion Control Software running in the Motion Control Computer. Hence as the foot brake (or other control) is depressed a point is reached when the deceleration reading does not increase, the Motion Control Software may turn on a visual (i.e. a LED or other light emitting device, preferably red in colour, and readily seen by the operator, without looking away from the windscreen etc), and/or

audible warning (i.e. high pitched tone etc, typically the pitch of the tone rising as the difference between the actual deceleration, and that predicted widens).

In a further implementation to that described above, a transducer (piezo ceramic, solenoidal, or voice coil etc) is attached to or mounted inside the foot brake. Should any unexpected loss of acceleration occur as described above, a voltage and or current waveform may be applied to the transducer under the control of the Motion Control Software. Such that it will generate a vibration or shock wave in the foot brake hence providing tactile feedback to the operator's foot on the foot brake (or hand on a joystick).

A further implementation may include any combination of audible and visual or tactile warning signals.

In another implementation during acceleration, the Motion Control Software is able to calculate the mass of the vehicle (from the rate of change of the RPM values and the magnitude of the torques of the polyphase traction motors). Hence the Motion Control Software may calculate the maximum rate of deceleration, and if the measured rate of change of speed during deceleration exceeds some specified fraction of this, the Motion Control Software may generate a warning signal as described above and or reduces the braking effect so as to ensure reliable braking.

In another implementation similar to the above an accelerometer similar to that referred to as be accelerometer X in one of the above forms may be fitted in the vehicle. Hence as the vehicle is accelerating, the output of accelerometer X may be used by the VCS (or other software) to determine the maximum values of acceleration Accmax of the vehicle.

Hence when the vehicle is decelerating, during braking, it the modulus of the deceleration, as detected by accelerometer X, Dcc, exceeds some specified fraction of Accmax, the VCS or other software may generate a warring signal as described above.

4. Handbrake

The handbrake is used here to denote a second braking control with its own sensor, such that should the sensor (or other part) of the foot brake control system fail, there is a second method of applying brakes.

In one form, the handbrake as described here may appear similar to that of a conventional vehicle, i.e., the braking force provided by it is some pro-rata function of the force applied to it by the operator. It may have a lock mechanism such that it can be locked in some position on a permanent basis (i.e., when parked, etc). This form of the handbrake will typically use one or more springs, acting to return the handbrake to its rest position. The handbrake may be fitted with a force sensor, the output of which is input to the vector control software, which is input to the vector control software, which in turn controls one or more braking mechanism (friction, regenerative, etc) in each vector wheel module (or other wheel assembly), such a to slow or stop the vehicle.

In another form, the handbrake may be similar to above and use some computer method via the vector control software to communicate the force being applied by the operator to the handbrake to one or more of the braking mechanisms in each vector wheel module. However, this form of the invention may also provides a mechanical and or hydraulic and or pneumatic etc linkage to at least one of the braking mechanisms (typically the friction brake) such that should the computer means fail or otherwise, at least one of the braking mechanisms in the vector wheel modules or other wheel assemblies, may be activated such as to slow and or stop the vehicle.

In one form of the invention hydraulically and or pneumatically operated disk brakes similar to those used in a conventional vehicle) may be used. In this form of the invention two distinct methods may be provided to operate the brakes. Firstly, each vector wheel module (or other wheel assembly) may contain a pump (hydraulic and or pneumatic) driven by an electric motor or other electrical means under the control of the slave control computer, from the vector control software in the Motion Control Computer. Additionally, a pipe or other means may be provided to interconnect the output of a manually operated pump (or via some force multiplying mechanism) from one or more of the operators braking controls, such as to supply pressure to the brakes.

5. Beyond Zero Regenerative braking (BZR)

In one form of the invention with for example a polyphase induction traction motor, then as the vehicle slows down the braking effort due to regenerative braking is maintained as the speed approaches zero due to the reversal of the direction of rotation, of the rotating field within the polyphase induction motor, i.e. in normal regenerative braking, when the RPM of the polyphase induction motor falls below its slip RPM, then the braking effort falls off. In BZR the braking effort due to regenerative braking is maintained, due to the reversal of the direction of the rotating field such that, even as the speed approaches zero, the algeraic different between the RPM of the rotating electrical field, and the actual RPM of the rotor (and hence its shaft etc) can be maintained should that be desired.

6. Brake Light

In one form of the invention an accelerometer, referred to here as accelerometer X, may be attached to the main structural frame (chassis) of the vehicle to measure its acceleration and deceleration along the direction of its major vector axis.

In this form a signal may be provided which is typically passed via a hardware or software logical "OR" such that when a deceleration above a certain specified value is detected the brake lights will illuminate.

Hence in this form the illumination of the brake lights, may be controllable by a number of means, including the deceleration of the vehicle as sensed by accelerometer.

METHODS USED FOR VEHICLE SPEED CONTROL

1. The Operators Acceleration Control and Acceleration

In one form of the invention, the operators speed control ie accelerator, consists of a pedal and spring similar to that in a conventional vehicle, such that if the foot is removed, it returns to its rest position. As well as the spring, there is also a sensor (angular or linear) such as to output a signal to the Motion Control Software running in the Motion Control Computer, so as to indicate the displacement of the accelerator pedal from its rest position. This signal is referred to here as Acc.

In the system used here:

Acc may equal 0 where the accelerator is in its rest position.

Acc may equal 1 where the accelerator is in at its maximum.

2. In one form of the invention the speed of the vehicle is controlled such that in the first instance its speed is proportional to the displacement of the accelerator, i.e. with the acceleration in its rest position, the vehicle is stationary.

If now the accelerator is displaced then the vector control software forces the VWM's, or other wheel assemblies, to increase the speed of the vehicle until its speed corresponds to the new position of the accelerator.

If the accelerator is held at a particular position the speed of the vehicle is also constant. Similarly, if the displacement of the accelerator pedal is reduced then the speed of the vehicle is also forced to slow (due to regenerative braking and or one of the other braking mechanisms) i.e. the accelerator may not only be used to increase the speed, (by increasing the displacement of the accelerator) or to hold a constant speed, (by a fixed displacement of the accelerator). Also if the displacement is reduced, then in the first instance the speed of the vehicle is also forced to reduce due to regenerative or other braking, i.e. the speed of the vehicle is a some function of the position of the accelerator, provided no force is applied to the brake.

In another form of the invention similar to the above, but now includes an idle speed feature, such that when the accelerator pedal is at its rest position, and with zero pressure on the brake, then the vehicle will move in the direction, as specified by the Forward / Reverse controlling at a speed referred to here as its idle speed (IS). If force is applied to one or more of the brake control then the vehicles speed is reduced, till at some force FIS, the vehicle stops, i.e. in this form the speed of the vehicle is again some direct function of the displacement of the accelerator, provided the speed is greater than IS, the idle speed, and provided no force is applied to the brake.

In another form, but now includes a mechanism such as a cylinder and piston arrangement with openings etc such as to allow the passage of air or liquid in and out of the cylinder such that the accelerators displacement can be increased rapidly, but should the foot be removed, from the accelerator, it returns at a slower rate, as its displacement decreases. The time constant, when its displacement is increasing being referred to here as its attack time constant TAM, and the time constant for the accelerator as its displacement reduces (i.e. when the foot is removed is referred to here as the decay time constant TDM.

In this form of the invention typically

TDM > TAM

where

TAM = the mechanical attach time constant.

TDM = the mechanical decay time constant.

Again in the first instance the speed of the vehicle is some direct function of the displacement of the accelerator, provided no force is applied to the brake. Also note if TAM and or TDM are short, then the Acceleration/Deceleration ability of the vehicle may not be such as to allow the speed of the vehicle to be such as to correspond to the accelerators position.

In another form of the invention similar to above, but which does not have a mechanical means to provide the attack and decay time constants, instead the signal from the displacement sensor on the accelerator, now passes via electronic or computer means such that it provides the attach time constant TAE and decay time constant TDE. Again in this form of the invention typically

where

TDE > TAE

TAE = The attack time constant due to the electronic or computer means.

TDE = The decay time constant due to electronic and or computer means.

Note that even though the accelerator may not have a mechanical means of providing additional mechanical time delays the accelerator mechanism itself may have delays associated with it, and referred to here as its natural attack time constant TAN, and its natural decay time constant TDN.

In this form of the invention, typically:-

TAE > TAN such that in this first instance that TAN may be ignored

also

TDE > TDN such that in the first instance that TDN may be ignored

3. Modification of the Primary Signal from the Accelerator

In one form of the invention similar to above, and where the output signal from the accelerator is in analogue form (or where it is passed via digital to analogue converter), one or more integrator circuits, typically consisting of a resistor and a capacitor are used to provide the time delay, then when the accelerators displacement is changed the relationship between the actual new position of the accelerator, and that of the signal provided to the vector control software (typically via an analogue to digital converter) will be of some exponential form, i.e. voltage corresponding to the actual new position of the accelerator will be approached in some near exponential relationship with time.

In one form similar to above semi-conductor components (current sources, operational amplifiers etc) may be added such that the relationship between the actual new position of the accelerator, and that provided to the Motion Control Software may be of some near linear characteristic.

ie., in these forms, analogue electronic delay circuits may be interposed between the source of the primary signal and the analogue to digital converter which feeds the vector control software.

ie., in the forms of the invention above a hardware module is interposed between the source of the primary signal and the VCS, such as to modify the primary signal.

In one form of the invention similar to above a software module referred to here as "Software Primary Modify Module" (PMM) may be run in the Motion Control Computer (or elsewhere) which modifies the primary signal before it enters the MCS proper. An example of this is where the primary signal from a accelerator displacement sensor with digital output (or of analogue form, which is passed via an analogue to digital converter) is used. Now this primary signal (of digital form) is modified such as to change the way the vehicle reacts, say for example if you remove your foot off the accelerator, while the vehicle was in motion.

In one form similar to above the Software Primary Modify Module (PPM), may introduce some time function such that now the Modified Primary Signal (MPS) output from the SPM is some function of time.

ie., MPS = f(t)

where	MPS	=	The modified primary signal output from the software primary modifying module
	f(t)	=	Some function of time, note, that this function may be of linear, or logarithmic or other form

In one form similar to above the function may be linear, such the modified primary signal (MPS) will have a constant rate of change as it approaches its final value, (which typically will be the primary signal from the accelerators sensor).

In another form similar to above the function may be of exponential, or logarithmic or other forms.

4. Psuedo Gearchange – Tight Loose Control (TLC)

In one form similar to above a control is provided, referred to here as the Tight Loose Control (TLC), the signal from the accelerators displacement sensor passes via software PMM whose operation is under the control of The TLC. When the TLC it is in its "tight" position, the rate of change of the MPS from the accelerators displacement sensors is very high (ie., time delay is short) such that the modified primary signal (MPS) is always nearly exactly the same as the primary signal from the accelerators displacement sensor, ie., the MPS is "tightly" controlled. Also when the TLC is in its "loose" position there is an appreciable time delay before the modified primary signal reaches it final value, (typically the primary signal, from the accelerators displacement sensor) ie., the MPS is "loosely" controlled. Additionally, this form may have provision such that the Tight Loose Control (TLC) may have a number of intermediate steps or settings (or may be continuously variable) between

its "tight" and "loose" position such the degree of "tightness" or "looseness" can be controlled by the setting of the TLC. Also in this form the relationship between the MPS and the primary signal from the displacement sensor on the accelerator may be some linear one.

In another form similar to above the function f(t) may be exponential or logarithmic or of some other form.

Hence the Tight Loose Control (TLC) may in fact act as a pseudo gear change mechanism, ie., when the TLC control is at, or near, its "tight" position, the vehicle may behave similar to a conventional vehicle in low gear.

ie., there is a "tight" relationship between the speed of the vehicle and the position of the accelerator.

ie., pressing the accelerator down may cause the vehicle to immediately accelerate, while releasing the accelerator, may cause the vehicle to slow down immediately, which is similar to that of a conventional vehicle in low gear.

Similarly if the Tight Loose Control (TLC) is put in a "loose" position, there will be a rather loose relationship between the speed of the vehicle and the position of the accelerator – similar to that of a conventional car in high gear, ie., there is not such a noticeable change in vehicle acceleration/deceleration as you change the displacement of the accelerator.

5. Active Control of the Accelerator

In another form of this invention the RPM status information received from all the vector wheel modules (or other wheel assemblies) may be used to control an acceleration simulation motor attached to the acceleration control so as to provide tactile feedback to the operator. Typically the acceleration simulation motor may consist of a polyphase stepper motor or Brushless DC motor, and its associated polyphase inverter/controller.

Typically the acceleration simulation motor may be, mounted on a strain gauge or other sensor or other means provided so as to measure the force being exerted by the operator on the accelerator pedal. Also a sensor (similar to in the above form) which measures the displacement of the accelerator pedal or control will be provided.

Consider a vehicle accelerating while travelling in a straight line, should the operator suddenly depress the acceleration pedal beyond the ability of the vehicle to accelerate, the Motion Control Software may apply such signals to the acceleration simulator motor to cause the pedal to feel harder, and secondly the Motion Control Software may still only increase the RPM commands to the wheels at a rate which all of the wheels can handle, by checking that the actual speed of each wheel in the status sent back from each vector wheel module or wheel assembly etc.

6. Accelerator Motor Alternator (AMA)

In another form of the invention, the operators accelerator control is connected (via gears, belts and pulleys, and or lead screw and nut etc) to a "accelerator motor alternator" (AMA) which typically

may be a polyphase stepper motor or BLDC motor. In this form of the invention a electrical load (i.e. resistors etc) may be provided across the electrical windings on the AMA, such that when the AMA is acting as an alternator (i.e. a source of electrical energy) its speed of rotation may be controlled by the magnitude of the electrical load.

Consider the accelerator say at fifty percent of its travel, then if the operators foot is removed from the accelerator, its return spring will force it to start moving towards its rest position, however now the time taken to return to its rest position will depend on the electrical load across the windings of the AMA, and the value of this load may be under the control of the vector control software such that the decay time constant TD of this form of the invention can be under the control of the vector control software which can also control the attack time TA of the accelerator in this form of the invention. Note that in this form of the invention that the AMA may only ever operate as an alternator, i.e. a source of electrical energy.

Hence this form of the invention provides a means of controlling the attack time constant TA and decay time constant TD of the accelerator. Hence if a TLC is provided, and by analogue means or via a software module in the MCS, the TLC controls the magnitude of the electronical load across the AMA, then the TLC will act somewhat as a pseudo gear change.

7. Accelerator Control Motor

In another form of the invention similar to the above, but now the motor controlling the position of the accelerator is referred to here as an accelerator control motor (ACM) which has its own polyphase inverter / controller which is under the control of the vector control software, such that all aspects of the movement of the accelerator pedal can be controlled.

In this form of the invention, the ACM is directly controlled by analogue means or a software module in the MCS, which in turn is under the control of a TLC, such that the TLC acts as a pseudo gear change. One or more accelerator return springs may also be used. Additionally, in this form of the invention, the vector control software may not only control the attack and decay times of the accelerator control but also its position, such that the position of the accelerator corresponds to the actual speed of the vehicle.

In another form of the invention, the motion control software contains code, which causes the application of the control signals to the polyphase inverter / controller of the ACM such that it, can for example, act to tend to prevent the accelerator being pressed down at a rate which is beyond the ability of the VWM's to accelerate the vehicle, i.e. if the force being applied by the operator to the accelerator is such that the accelerator pedals displacement is increasing at a rate beyond the acceleration capability of the vehicle, then the Software Primary Modify module in the motion control software may cause the ACM to apply a force to the accelerator such as to act to prevent or at least reduce the rate at which the accelerator displacement is increasing. This acts as tactile feedback to the operator,

who will sense it as a "hardening" of the accelerator, such as to inform them of this situation, i.e. that they are demanding acceleration, beyond the ability of the vehicle, under the existing conditions.

8. Constant Speed Operation

In one form of the invention when the vehicle is required to operate at a constant speed. First the operator presses the accelerator till the desired speed is reached, the operator then actuates a "lock mechanism" such as to physically lock the accelerator in its current position. The lock mechanism is such that the operator can unlock it and so return to normal operator by simply pressing the accelerator.

In another form of the invention, when the vehicle is operating at the desired speed, the operator presses a button or switch or other sensor, the output signal of which among other things, cases a electrically operated mechanism to lock the accelerator in its current physical position. At this time, a led or other visual indicator may illuminate or otherwise display, such as to indicate that the vehicle is in constant speed mode. To release the vehicle from the constant speed mode, the operator simply presses the same, or another, button or switch or sensor, which causes the led or display to indicate that the vehicle is no longer in constant speed mode, and to release the electrically operated lock mechanism, such that the accelerator can be moved normally.

In another form of the invention similar to the above, the sensor used to cause the lock mechanism to release the accelerator, is itself mounted in the accelerator, such that when the operator wants to exit the constant speed mode, they simply tap the accelerator with their foot. Note this form of the invention also includes a time delay, such that when the operator enters the constant speed mode they have time to remove their foot etc from the accelerator, before the release in the accelerator becomes active.

In another form of the invention, similar to above, the accelerator motor alternator (AMA), which is typically a polyphase stepper motor or brushless DC motor (BLDC), acts as the electrically operated lock mechanism.

In another form of the invention, similar to the above, the actual speed required for the vehicle is entered via a keypad or keyboard into typically non-volatile memory such as flash or EEROM etc such that digital details of the speed are provided to the vector control software, so as to allow it to operate at that speed once a button or switch etc is actuated, and similarly to exit the constant speed mode when the same or another button or switch is actuated. This form of the invention may use the accelerator motor alternator (AMA) to move the accelerator to the position, corresponding to the speed as specified by the digital means.

FORMS OF THE VECTOR WHEEL MODULE AND WHEEL ASSEMBLIES

1. Low Unsprung Weight Versions of VWM

In this form of the invention springs or other suspension items are interposed between the wheel and some of the heavy items within the VWM such as the polyphase traction motor, the energy storage devices (batteries, ultracapacitors) etc, hence there is less weight "below" the springs, and hence

generally has lower unsprung weight. This form of the invention has particular advantages for example when travelling on uneven road surfaces, particularly at speed. Additionally this form has the advantage of subjecting the batteries, ultracapicators, etc, to less vibration etc, and hence they typically may a longer lie expectancy.

2. High Unsprung Weight Versions of VWM

In this form of the invention no springs or other suspension items are interposed between the wheel, and some of the heavy items within the VWM, such as the batteries, ultracapicators, etc. This form of the invention also has a number of advantages, ie the springs and other suspension components may now be smaller (as they do not carry the batteries and/or ultracapacitors, etc.) hence their design can be optimised to provide more comfort for the passengers. Additionally this form has particular advantages in slow speed equipment which require a low center of gravity.

3. Twin Wheel Assembly Same Side (TWS)

In one form of the invention, one polyphase traction motor (PTM) is used to drive two wheels on one side of the vehicle and another PTM drives two wheels on the other side of the vehicle. The drive between each PTM and its two wheels is typically via an arrangement of belts and pulleys and/or gears and shafts and/or chains and sprockets. Each of the PTM's typically may have its own polyphase inverter/controller such that the RPM of each PTM, and hence its two wheels, may be adjusted independently of the RPM of the other PTM, and hence its two wheels, such that the relationship between the RPM of the wheels on opposite sides of the vehicle may be controlled by computer means so as to allow operation in cruise mode and crab mode as described elsewhere in this patent application. This form of the invention where one motor is used to power two wheels on the same side of a vehicle is referred to here as a Twin Wheel Assembly Same Side (TWS).

Each PTM will typically have it's own polyphase inverter/controller which may be mounted immediately adjacent to, or mounted on or within, the PTM. Additionally, an energy storage device (e.g. battery, super capacitor, ultra capacitor, etc.) may be mounted immediately adjacent to the polyphase inverter/controller and its associated PTM.

Additionally, in this form of the invention the arrangement of the PTM's and their associated polyphase inverter/controller may be such as to allow a single energy storage device (or arrangement of energy storage devices) to be mounted such that it is adjacent to the polyphase inverters/controllers in two TWS, each being on opposite sides of the vehicle.

In one form of the invention similar to the above, each of the four wheels has its own "constant velocity" (CV) linkages, to transfer tractive torque to a wheel, such that each of the wheels may be steered while one end of the CV linkage retains its position relative to the chassis of the vehicle, so as to allow for the transfer of power via belts and pulleys and/or gears and shafts between the PTM and the wheels.

Thus, in this form of the invention the PTM's may each be rigidly mounted (or substantially so) to the chassis of the vehicle.

Typically, each of the four wheels may have a suspension similar to that on the front wheels of a conventional front wheel drive (or four wheel drive) vehicle.

In one form of the invention similar to the above, a PTM with dual rotors and with single or dual stator such as a dual rotor motor (DRM) or an antidirectional twin rotor (ADTR) motors, etc., may be used.

In one form of the invention similar to the above, the motors used, may contain one stator but two rotors and two shafts. This motor is referred to here as a dual rotor polyphase motor (DRM) and is described in more detail later in this patent application. Additionally, each of these DRM may have only one polyphase inverter/controller.

In this form of the invention one of the DRM drives two wheels on one side of the vehicle. One of the rotors, via its shaft and power transmission components, drives the front wheel and the other rotor, via its shaft and power transmission components, drives the rear wheel. Similarly, another DRM may drive two wheels on the other side of the vehicle with each wheel being driven by its rotor via its shaft, etc.. Since each DRM may contain one stator with one set of stator windings and may be driven by one polyphase inverter/controller which may have the same number of phases as the DRM, there is one rotating field produced within the DRM. Hence, typically both rotors, and hence their shafts, will rotate at approximately the same RPM. The RPM of each may differ slightly due to "electrical slip" etc., depending on the load applied to each wheel, and hence its rotor. This is particularly the case when dual rotor polyphase induction motor is used.

4. Twin Wheel Assembly Opposite Side (TWO)

In a different form of the invention a dual rotor motor (DRM) with single stator may be used to drive wheels on the opposite side of the vehicle.

The disadvantage of this form of the invention is that it is difficult to force wheels on opposite sides of the vehicle to turn at different RPM other than by resorting to the use of friction braking techniques, etc., i.e. the techniques typically referred to as ABS, etc.

In another form of the invention a vehicle may have wheels on opposite sides of said vehicle driven by a DRM with two rotors and two stator windings. The two windings are supplied from a common polyphase inverter/controller but with additional circuitry such as resistors, etc. interposed in the wires from the said polyphase inverter/controller to one or both of the stator windings.

In another form similar to above, switches or relays, or solid state devices such as Field Effect Transistors (FET's) or IGBT's, etc., may be used to control the magnitude and/or phase etc., of the polyphase currents flowing in the wires, so as to control, for example, the amount of braking force generated by one rotor and its wheel relative to the other rotor and its wheel.

In a different form of the invention, two wheels on opposite sides of a vehicle are driven by a DRM with two rotors and two stator windings. Each stator winding is supplied with polyphase currents from its own polyphase inverter/controller so as to allow independent control of the RPM of each of the rotors, and hence of the wheel being driven by that rotor.

1. Speed Control of the Polyphase Traction Motors

In one form of the invention the polyphase traction motors may consist of a polyphase induction motor. This form may not use any other means of controlling the RPM of the motor (and hence the wheel) other than by controlling the frequency of current waveform applied to each of the phases of the motor by its polyphase inverter / controller, in an open loop manner.

Typically, induction motors have electrical slip; i.e. the actual RPM of the polyphase induction motor may differ from the "synchronous" RPM by some amount (typically of the order of 5% at the motors nominal operating RPM). Hence, this form of the invention the actually RPM of the motor and hence the wheel may differ from the synchronous RPM.

Typically this form of the invention will contain one or more RPM sensors, which many times per second, will provide details of the actual RPM of the polyphase induction motor (and hence the wheel) to the Vector Control Software running in the Motion Control Computer. In the first instance this RPM status information may only be used to check if a fault has occurred in the polyphase induction motor and its polyphase inverter / controller etc. i.e. the vector control software may only check that the RPM of the polyphase induction motor is within the specified limits of electrical slip for that motor.

In another form of the invention similar to above, a polyphase induction motor may again be used. How however RPM sensors and a feedback loop, and other computer, circuitry may be provided within each of the vector wheel modules such as to hold the RPM of the induction motor within some specified tolerance of the command value received from the vector control software, by the slave control computer in the VWM (or other wheel assembly). Again each of the vector wheel modules (or other wheel assemblies) may provide status information many times per second which informs the Vector Control Software of the actual RPM of the polyphase induction motor.

In another form of the invention polyphase brushless DC motors, or polyphase stepper motors etc may be used. Again they may contain RPM sensors, which many times per second, may provide details of the actual RPM of these Motors (and hence the wheel) to the Vector Control Software running in the Master Computer, such that should such motors fail or their RPM deviate from its specified value, appropriate action can be initiated by the vector control software.

Typically in all forms of this invention the RPM status information will be used by the Vector Control Software to display status of the vehicle including fault and warning displays, typically indicating the current status of all of the vector wheel modules.

2. Power Transmission

The power transmission referred to is that which may be interposed between the polyphase traction motor and the wheel. Typically, it may be identical in each of the VWM's (or other wheel assemblies) on a vehicle. Typically all forms of it consist of some mix of belts and pulleys, sprockets and chains and gears of various types and also splines, constant velocity linkages and similar parts which allow the movement of one part relative to another without disruption of the transmission of power between the two parts.

In another form similar to above, it may contain means such as to disrupt the transmission of power, such as for example to allow the change of ratio of gears etc.

A polyphase traction motor may be coupled directly to the wheel, such that belts, gears, pulleys and the like are not required.

Movement of the vehicle in a reverse direction, typically will be provided for by a deceleration of the polyphase traction motor, then changing the (typically only one) bit in the command word to the polyphase inverter (associated with each polyphase traction motor) which specifies clockwise / counter clockwise rotation of the motor i.e. typically a gear change is not used to change the direction of the polyphase traction motors in the VWM's (or other wheel assemblies) and hence the vehicle from forward to reverse and vice versa.

The RPM sensors on the polyphase traction motors may be capable of detecting the sense of the polyphase traction motors rotation (i.e. clockwise / counter clockwise) in addition to the magnitude of the RPM, hence the status information sent back to the vector control software allows it to check that all of the polyphase traction motors are turning in the correct direction.

Where the power transmission does include a ratio change mechanism typically in all of the VWM's on a vehicle, sensors will be provided which give detail of the status of the ratio change mechanism and this will be included in the status to the vector control software such that it can check that all VWM's (or other wheel assemblies) have the correct ratio, and that it can display appropriate warnings if this is not the case.

In one form of the invention, no allowance is provided to allow a change of the (typically reduction) ratio between the polyphase traction motor and the wheel.

In another form of the invention provision is made to change the gear ratios which constitute part or all of the power transmission in a gear box or similar.

In another form of the invention provision is made to "lock" an arrangement of gears which constitutes part or all of the power transmission such that in one state it allows relative rotation of the input gear to the output gear (or gears) such that say a reduction rate n:1 occurs, while in the other state, relative rotation of the input gear to the output gear or gears is prevented by a lock or similar mechanism such that the ratio between the input gear and the output gear or gears is 1:1. One example of which is to consider a VWM (or other wheel assembly) which uses a hub assembly (to which the wheel mounts), which contains a planetary or other gear arrangement of one or more stages, where

provision is made to lock the input of one stage to its output or the output of one of the other stages (for a multistage planetary hub). The "lock" mechanism may consist of a pin or similar with action similar to that of a "dog clutch" where typically the input shaft needs to be stopped, or at least at slow speed, before the "lock" is either locked or unlocked, so as to prevent a mechanical shock being generated.

In another form of the invention an arrangement is provided which is similar to the above, but in this form one or more clutches are used which contain a friction disk or drum etc such that the energy which would otherwise be dissipated as a mechanical shock, can now be dissipated. Additionally due to the precise nature of the speed control of the polyphase traction motor, it is now possible to minimise the amount of energy which is lost as heat in friction, by the rapidly acceleration of the input shaft due to "motor action" of the polyphase traction motor, or due to regenerative braking of the polyphase traction motor, during the small time interval, while the ratio change occurs.

In another form of the invention provision is made to change the ratio between the shaft of the polyphase traction motor and the wheel by, mechanical disengagement and engagement of two or more gears, where the number of teeth on at least one of the gears changes as a result of the disengagement and the engagement. Sensors may be provided on the input and output shafts, such that the exact speed (and also typically the tooth position) of each is know at any instant, and as the number of teeth on each gear is known to the gear change software, such that it can control the speed (and also phasing if required) of the gears being engaged such as to ensure a smooth ratio change with a minimum of mechanical shock. A stepper or (other motor) and a lead screw and nut type mechanism or a solenoid may be used under the control of the gear change software, to move the gears relative to each other so as to effect the change of ratio. One or more of the gears may move axially, such that the direction of rotation of the polyphase traction motor remains the same, as does the direction of rotation of the wheel.

ADDITIONAL METHODS AND MEANS

1. Variable Shape Vehicles (VSV)

Commercial applications for vehicles of variable shape or geometry include mobile cranes (particularly large ones), "cherry pickers", drilling rigs for mining and oil exploration, fire engines for use with multi-story fires, armoured personnel carriers etc.

These can serve as an example of the use of this invention. For example large mobile cranes, typically have outriggers (or extensions) which are set in their "retraced position" such as to reduce the width etc of the vehicle so as to travel on roads. Once they arrive at the work site, the outriggers (extensions) are typically folded out or extended by hydraulic rams etc (and a Jack or other means extends to make contact with the ground such that the crane will be stable when for example lifting loads which are located near the limit of the cranes reach. Typically it is difficult to make the outrigger arms large enough to ensure stable safe operation of the crane, yet small enough (when retracted or folded or otherwise) to travel on normal roads.

In one form of the invention one or more VWM's are used at the end of each outrigger. Typically the outriggers would be attached to the chassis by some pivot type mechanism. Typically, as is common practice at present, the outrigger arms can be telescopic such as to reduce their size when in transit to a site. In this form of the invention the outrigger arms may be extended (retracted), and pivoted by using the tractive force exerted by the VWM, as each arm is independently (or all arms collectively) extended / retracted and pivot such as to achieve the desired shape, typically the arms are now locked in place. The crane may be driven around the site, and may also be, used to carry loads (as specified in its regulations) while it has the outriggers extended, thus providing flexibility, and speed of operation.

In one form of this invention as described here, the "outrigger arms" may be larger, than is possible with existing designs. Typically some of the outrigger arms may be larger than other arms, such that the jib etc is stored above the larger arms when in transit.

In another form of the invention similar to the above jacks or other means may be provided at the end of each outrigger arm so that they can be extended to provide an even more stable platform where heavier loads etc need to be lifted, now however typically it will not be possible to move the crane, while carrying the load.

In a further form of invention, with telescopic arms, similar to that described above, but now with hydraulic rams or linear electric actuators, motors ropes and pulleys etc to extend and retract the telescopic arms.

For use with armoured personnel carriers and other military vehicles, the VWM's may be mounted on the ends of arms, which may be extended such that the VWM's (and hence the wheels) are some distance from or below the MSF or hull of the vehicles. Hence should a wheel of the vehicle strike a land mine or similar there will be a much improved chance that the occupants of the vehicle will survive the explosion.

Typically the vehicles will be able to retract or fold the arms such that its size is reduced considerably, when operating in areas believed to be free of mines.

Additionally this form of the vehicle may have the ability to retract or fold the arms (and hence wheels) even further such as to allow a compact form of storage on marine vessels, aircraft etc. This form has another advantage in that if built in amphibious form, when in the water, with the wheels in this fully retracted position, they may cause a minimum of water resistance, hence allowing higher speed operation.

2. Modified Primary Signal (MPS)

In one form of the invention the terminology Modified Primary Signal (MPS) is used to refer to a primary signal (such as that from the displacement sensor on the accelerator) after it has passed through a Primary Modification Module (PMM) which contains electronic means and or software and computer means, such as to modify the primary signal.

In one form of the invention the Primary Modification Module (PMM) may exist as a separate hardware and or software and computer means.

In one form of the invention the Primary Modification Module (PMM) may exist as an integral part of say the Motion Control Computer and or the vector control software.

An example of a modified primary signal is, the modified primary signal from the accelerators displacement sensor, after it has passed through its PMM and been modified etc according to say the position of the TLC control.

3. Modified Secondary Signal (MSS)

In one form of the invention the terminology, Modified Secondary Signal (MSS) is used to refer to a secondary signal (such as the RPM commands from the VCS) after these have passed through a Secondary Modification Module (SMM) which contains electronic means and or software and computer means, such as to modify the primary signal.

In one form of the invention the Secondary Modification Module (SMM) may exist as a separate hardware and or software and computer means.

In another form of the invention, similar to the above the Secondary Modified Module (SMM) may exist as an integral part of say the Motion Control Computer and or the vector control software.

4. Cruise Crab Control

This operator control is used to select between cruise mode and crab mode, in addition to typically controlling other aspects of the vehicle.

In one form of the invention the cruise crab control may consist of a knob, similar to that often used for changing gears (manual or auto) in a conventional vehicle. However now the knob may have built into it or adjacent to it four buttons or protrusions, arranged in a regular pattern around the major axis of the shaft on which this knob is mounted. Additionally these buttons or protrusions will typically lie in the same plane, which typically will be parallel to (or at least significantly so) the plane on which the vehicle rests.

Two of the buttons or protrusions, referred to here as the cruise buttons, are arranged such that the line joining them is parallel to the major axis of the vehicle, and similarly the line joining the other two, referred to here as the crab buttons, will be at right angles to the major axis of the vehicle. Additionally a mechanism will be provided which mechanically or otherwise, interconnects these buttons such that if one or both of the cruise buttons are pressed in, that both of them will move inwards, and the two crab buttons will move outwards. Similarly if one or both of the crab buttons are pressed inwards, that both will move in and both the cruise buttons will move out. Typically each of the crab buttons will be marked with the word "crab" or "yaw" (in the appropriate language of the country) or with a picture or other representative of crab or other symbol, etc, such that when the crab buttons are "out", that this picture, word (or other symbol, i.e., a sideways pointing arrow), or some mix of these will become visible, such that when one or both of the crab buttons are pressed in, that the

crab marking etc may become hidden or obscured, and the word "cruise" (again in appropriate language) or a picture of a cruise liner or car or arrow etc or other suitable representative will become visible. Typically the major axis of the cruise liner or car or arrow etc will be parallel to the major axis of the vehicle in which this cruise crab control resides. Additionally the crab picture (or representation) if used will be oriented such its mouth and eyes are facing in the forward direction of the vehicle and its rear is facing rear.

Also the cruise crab control will contain one or more sensors (i.e. switch, hall effect device, opto device etc) such that when significant force is applied to the cruise buttons the sensors, impedance to electrical current, changes such that it indicates to the computer means etc associated with this cruise crab control, that it is now in crab mode. Similarly the sensors impedance to electrical current changes to some other value when the crab buttons are pressed in, such as to indicate cruise mode. Alternatively, the sensor may be such as to change the strength of an electric or magnetic field or electromagnetic radiation (ie infrared or light etc) which in turn will cause the current or voltage (or some other physical phenomena) to change at the input to the computer means such as to indicate the state of the cruise crab control, which will typically contain an "over centres" or similar means such that when sufficient force is applied to the cruise or crab buttons, that tactile feedback is provided to the fingers etc such as to indicate that the state of the cruise crab control has changed. Additionally that typically this change of state will also be indicated on the control panel or display of the vehicle, by visual or audible means etc.

In another form of the invention the cruise crab control may be provided in an electronic display (typically a computer means, similar in general appearance to that described above. Button, pads or other sensors (including the use of a "trackball" are provided to indicate cruise or crab mode, either by the shape, or colour or intensity of the light emitted by the display such as to indicate the mode. Additionally this form of the invention (or the previous) may indicate the mode by an audible sound, ie pitch of a tone etc, or music or song or spoken word etc.

In another form of the invention, multiple cruise crab controls may be provided.

5. Data Communication Network (DCN)

The DCN is used for data communication throughout the vehicle, and in particular to the communicating with the VWM's (and/or other wheels assemblies), the sensors, transducers, motors, display panels, controls and other equipment referred to in this invention. It may use fibre optic or, conventional cable or some mix of both.

In one form of the invention it may consist of a star network (or multiple star networks for redundancy) with the star point located at the input / output ports of the Motion Control Computer, on which the vector control software runs.

In another form it may consist of a bused (also referred to as multidrop or daisy chain) networks or multiple networks (for redundancy).

In another form it may consist of some mix of star and bused networks.

6. Cooling

In one form of the invention each VWM (and/or other wheel assemblies) has a cooling system using pressurised, filtered cooling air. The major purpose of this air is to cool the heat producing component located within the Vector Wheel Module (or other wheel assembly), additionally due to the pressure of the filtered cooling air, it helps prevent the ingress of dust, moisture, etc.

In one form of the invention the cooling system for the Vector Wheel Modules, etc., simply consist of one or more fans each with a filter, the fans and these filters typically being located within the upper part of the VWM, etc. There may be an exhaust duct, again in the upper part of the VWM, etc., which may be angled such (or by other means such as screens etc) that as far as practical the exhaust air does not enter the intake. Typically the fans will be electrically operated off the VWM's, etc., power bus. Typically, these fans will be under the control of the VWM, etc., vector Control Computer (VCC) such that it can control the speed or duty cycle or both of the fans, so as to prevent the temperature from rising above some specified value. Typically air flow sensors will also be provided within the VWM, etc., such that should the filters become blocked, this will be detected by the VWM, etc., Vector Control Computer (VCC) which will send back "Filter blocked" status to the Vector Control Software in the Motion Control Computer (this may be a single bit or multiple bits, i.e. indicating the degree of blockage which will display this status to the operator such that the filters on that VWM, etc., can be cleaned or replaced before a problem occurs. Additionally this Filter blocked Status may be stored in the Flash or to the non-volatile memory along with the ID of that VWM, etc., in which the fault occurred, and also with a time and date for maintenance purposes.

Also should the temperature within the VWM, etc., start to rise above normal, the VWM, etc., Control Computer may maximise the cooling effect by turning all its fans (if more than one) on to maximising speed and maximum duty cycle etc.

In another form the cooling system may be similar to above, but with the filtered pressurised air supplied from a system of fans and filters located in the upper part of the vehicle. The filtered air being distributed to each of the VWM's (or other wheel assemblies), etc., by pipes and ducts. Typically the pressure of the air being low, i.e. only sufficient to prevent the ingress of dust etc.

In a further form of the cooling system intended for use on vehicles in difficult terrain etc, the VWM's, etc., may be sealed apart, from the air inlet pipes from the pressurised filtered air source in the upper part of the vehicle. And the exhaust part from each VWM, etc., typically going to a point in the upper part of the vehicle where the air exhausts via a pressure relief valve. Typically the air pressure in the VWM, etc., cooling system may be such as to prevent water entering the system, should a hole or other opening be present. That is, the air pressure would be such that typically the air would exit, rather than the water enter the VWM, etc. Typically once the need for amphibious or similar operation ended, the Vector Control Software would send a command to open the pressure relief valves (i.e. via a

solenoid or motor) such that the pressure of the filtered cooling air system falls to a low value (and hence the energy needed to pressurise it, drops to some small fraction) but sufficient still to prevent the ingress of dust etc.

In another form of the invention a sealed, closed cooling system uses, typically inert non-toxic gas, which is cycled through the VWM's, etc., then passes through a heat exchanger before continuing to cycle through the VWM, etc, again.

In another form similar to above a refrigerant or other liquid (which typically may have a boiling point between 40°C and 90°C) is pumped through a network of pipes to the VWM's (and other wheel modules, etc) where typically it vaporises and returns to a heat exchange in the MSF, where it is condensed to a liquid, before being pumped back to the VWM's (or other wheel assemblies), etc.

In another form of the invention similar to above, the cooling system may use a liquid i.e. water or more preferably a liquid which is inert, non toxic and a non-conductor of electricity. Pumps being used to cycle it via a network of pipes through the VWM's, etc., the heat exchange in a manner similar to the cooling system above. Typically this liquid will have a boiling point greater than 90°C, such that the intention is that the liquid may not boil.

In another form of the invention the cooling system consists of a mix of gas and liquid cooling systems where typically one or more enclosed modules within the VWM, etc., i.e. the motor, the polyphase inverter / controllers, computer means etc and possibly any arrangement of belts and pulleys (particularly if high speed) may be cooled by a gas, preferably inert, non toxic typically under pressure. Typically the gas filled enclosed modules would operate at a pressure greater then one atmosphere, and would each be fitted with a pressure sensor, such that its status can be read by the slave control computer in the VWM etc. and sent back to the Vector Control Software, such that a warning etc can be raised for the operator, should the gas pressure in a module fall below some value.

The cooling liquid (which may be a refrigerant and or may have a boiling point greater than 90°C) typically pumps may be used to cycle it via a network of pipes through the inside of the VWM, etc., (around and/or through the enclosed modules) to remove heat which is carried out to a heat exchanger, or other means in the MSF of the vehicle, the liquid continuing to cycle around.

In another form of the invention similar to the above, the enclosed gas filled modules within the VWM, etc., may have a pipe or other connection, typically to a gas reservoir located within the VWM, etc., may would be fitted with one or more pressure sensors to send statistics such as the pressure back via the slave control computer to the Vector Control Software. Typically the gas pressure sensors may be of pass/fail type or able to indicate the gas pressure such that the status of the pressure can be monitored via the SCC and hence by the Motion Control Computer so as to detect a leak hopefully at an early stage before it becomes a problem additionally a combination of pass / fail and a "linear" or multiple level sensing sensors may be used.

In one form of the invention, similar to the above the heat exchanger may sink the heat into a thermal mass such as a eutectic salt, or into ice or liquid hydrogen, or nitrogen etc.

7. Electromagnetic Compatibility - (EMC)

EMC is a legal requirement in many countries through out the world.

Typically the polyphase inverters and controllers, used with the polyphase motors, in addition to generating the desired electrical signals, also generate other frequency components which may prevent the product from meeting the EMC requirement.

In one form of the invention each of the polyphase traction motors, and their associated inverter / controller typically has its own significant energy storage devices (batteries and or ultracapacitors, etc.) mounted in the Vector Wheel Module (or other wheel assemblies), immediately adjacent to the polyphase inverters and motors etc.

Hence the power conductors between the motor, its inverter, and its batteries and/or ultracapacitor are all short. In this invention, typically the length of these conductors is a small fraction of the wavelengths of the electromagnetic components generated by the inverter / controller, which if radiated, could constitute an Electromagnetic Compatibility problem.

This gives a significant, advantage to this invention over other products, in its ability to comply with EMC regulations (in addition to other benefits) in that it reduces the amount of electromagnetic radiation from each VWM or other wheel assemblies, and hence from the vehicle as a whole.

The design of the polyphase inverter circuits which produce the polyphase drive currents for the polyphase motors, may be such as to minimise the generation of frequency components, to as low a level as possible, commensurate with efficiency and other considerations.

In one form of the invention conductors of sufficient width may be used, and in particular between the motor the inverter and the energy storage devices/batteries/ultracapicators. And that typically all, or a significant part of these conductors, will consist of sheet metal, copper laminate on a pcb, woven wire etc. The width of these conductors may be a significant percentage of their length, so as to minimise the inductance and hence the impedance of these conductors.

As a result, the impedance of these conductors, may typically be some fraction of the internal impedance of the energy storage devices (batteries and/or ultra capacities etc), thus allowing the energy storage devices to act as an effective sink for the currents, which if radiated could constitute an EMC problem.

One form of this invention will typically use energy storage devices (batteries and/or ultra capacities etc) whose internal impedance is low.

Additionally that typically this invention will use inductors, capacitors, or other devices such as filters, in the "DC supply lines", which pass from the rest of the vehicle to the VWM's or other wheel assemblies, so as to further reduce the amount of electromagnetic radiation.

In one form of the invention, in the first instance, all wiring and electronic and electrical components etc will be insulated from the outer shell of the vector wheel modules (or other wheel assemblies, etc). This outer shell (or enclosure) may typically be constructed from metal, or other electrically conductive material. Materials such as plastic or fibreglass etc may also be used to which a coating of conductive material has been applied to form a screen and hence reduce the level of electromagnetic radiation.

Typically some of the components within the VWM's or other wheel assemblies, will themselves, have their own partial, or full electrically conductive screen, i.e. the external metal surface of the polyphase motor, in itself forms a screen of sorts.

One form of the invention will use of a number of electrically conductive screens, as described above, each of which in the first instance are electrically insulated from each other, such as to allow the selective bonding (electrical interconnection) of these screens and components to each other, so as to ensure minimal leakage of electromagnetic radiation. At some stage during the engineering development of the product a specific interconnection system will be implemented, so as to meet these and other objectives.

8. Operator Seating Control and Displays etc

In one form of the invention, the operators seating, control and displays remain fixed, irrespective of the operating mode.

In another form of the invention, the operators seat and at least some of the operator controls, and displays move to the current angular setting of the mode. Typically this will be due to the above being mounted on a "turnable" or turret etc such that they can pivot about some point. Typically an angular displacement sensor will be provided such as to provide details of the current position of the turnable or turret, to the vector control software. Also an electric motor may be provided which can rotate the turntable or turret to the desired position under the control of the vector control software.

Another form of the invention, may have provision such that for example when the spin on a spot (S0S) feature of the cruise mode is used, that the operators seating and controls remain stationary, and it is the MSF etc of the vehicle which moves. Typically they may be fitted with a “closed circuit TV” and monitor such that the operator can observe the operation of some bucket or other attachment which does move with the vehicle.

9. Motor with Integral Energy Storage (MIE)

Typically the energy storage devices (batteries and/or ultracapacitors, etc.) in this invention are located as close as practical to the polyphase traction motor and its polyphase inverter / controller. Note that typically the polyphase inverter / controller is also located immediately adjacent to, or mounted, on or inside the polyphase traction motor.

In one form of this invention, batteries and or ultracapacitors are mounted around, or on one end of or inside a polyphase motor, and it's polyphase inverter / controller. The motor with battery and/or

ultracapacitors being referred to here as a motor with Integral Energy Storage (MIE). One of the advantages of the MIE is the short length of the conductors between the energy storage devices and the polyphase inverter / controller and the polyphase motor.

10. Axial DC Electrolytic Capacitors (DEC)

These components which can be used as part of this invention and also as an invention in their own right consist of an electrolytic capacitor which allow direct current (DC) to pass through it, typically in an axial direction.

In one form of the invention, two conductors are provided, one of which is referred to here as the positive conductor and is typically marked with a "+" symbol on at least one of its ends, or at least adjacent to it. The other is the negative conductor and is typically marked with a "-" symbol. Typically these conductor's will be of aluminium or some aluminium alloy that is similar to that used in the foil in aluminium electrolytic capacitors (also commonly referred to as electrolytic capacitors or simply as electrolytic's). Alternatively they may have their surface covered with material of composition similar to the aluminium foil or alternatively have sheets of aluminium foil attached to each, but separated by an electrolyte similar to that used in electrolytic capacitors. The two conductors can each have one or more holes at each end, or other connection mechanisms so as to allow electrical connection to be made to each end, by bolts or screws or rivets or soldering or welding etc such that a direct current can pass from one end of each conductor to the other. Typically direct current (or current which at least has a significant direct component) passes through one of the conductor's, from say a dc power supply or source and goes to a load (say a polyphase induction motor and its polyphase inverter) and returns via the other conductor / electrode to the other side of the dc power supply or source. Typically the positive side of the dc power supply or source will go to one end of the positive conductor (referred to here as positive input, the other end of the positive conductor is connected to the positive side of the load. Similarly the negative side of the power supply or source connects to the negative input end of the negative conductor, the other end being referred to here as negative output, which typically connects to the negative side of the load. The positive input and negative input are at one end of the DEC, the positive and negative output being at the other end of the DEC. Hence this form consists of two conducts separated by an electrolyte, each of the conductors has one or more connection points at each end of the conductors, such that direct current can flow via the conductors from one end of the Axial dc electrolytic capacitor to the other. Also note that typically the two conductors are each of similar current carrying capacity, and that typically at least some versions of the Axial dc electrolytic capacitors will be capable of carrying direct currents of the order of tens of Amperes, or of hundreds of Amperes and more. Gas escape plugs or similar devices may also be fitted to the DEC.

In another form of this invention similar to the above, the foil used as the electrodes will itself (or at least some part of it) constitute the conductors which carry the (substantially direct current) from

one end of the DEC to the other. Typically tabs or other protrusions will be provided at each end of the DEC such as to allow current to flow. Additionally some type of an enclosure will be provided with seals at both ends etc so as to prevent the electrolyte leaking out. Gas escape plugs or similar mechanisms may also be provided.

In another form of this invention similar to above, a number (in some cases many), typically small conductors will be attached to one layer and protrude through both ends of the DEC such as to allow electric current to flow between the two ends of the DEC. (typically some rubber or plastic seal, etc., being provided at each end where the conductors protrude from the DEC). The other layer will be of similar construction. Gas escape plugs or similar mechanisms may also be provided.

11. Axial DC Ceramic Capacitors (DCC)

Another form of the invention similar to above, but now the conductors are typically made of copper or a copper alloy and the space between the conductors (or copper or other electrically conductive foil attached to the conductors) is filled with a ceramic dielectric, with metalized surfaces on each side etc such that one side connects to each of the conductors. The metalized ceramic is typically of high dielectric constant material, commensurate with the voltage it is specified to operate at. Additionally the metalized ceramic may consist of one large block or sheet, or of two or more (in some cases, many more) individual metalized ceramic blocks or sheets, each of which has one side connected to each of the conductors.

12. Lossy Transmission Line (LTL)

Those components can be used as part of this invention and also as an invention in their own right, and consist of a "axial dc electrolytic capacitor (DEC) or axial DC ceramic capacitor (DCC) as described earlier with ferrite or powdered iron etc around the outside of the DEC or DCC with the connection points exposed at both ends of the DEC or DCC .

In one form of the invention, the lossy transmission line (LTL) consists of a one or more ferrite (or powered Iron) toroids or sleves around the outside of the DEC or DCC such as to increase the common mode impedance of the conductors / electrodes in the DEC or DCC and also to increase the loss, across certain frequency bands of any current flowing through the conductors / electrodes which have frequency components within the frequency bands.

13. Multistage Lossy Transmission Line (MTL)

These components can be used as part of this invention, and also as an invention in their own right.

In one form of the invention the multistage lossy transmission line consists of two or more of the lossy transmission lines connected in series such that the output terminals, connect to the input terminals of the next stage, where DEC are used the polarity being kept the same, ie a positive output connects to a positive input etc.

14. Auxiliary Control Module (ACM)

In this form of the invention, a typically small auxiliary control module (ACM) is provided such as to allow control of one or more, but typically capable of controlling all, of the VWM's or other wheel assemblies on a vehicle.

Provision is made such that the ACM is typically portable and can be held and operated by one person if necessary or may be secured, typically on a temporary basis within the vehicle or external to it. Should a fault or other problem develop in one or more VWMs or TWS, etc., when they, or typically all of the VWM or TWS, are unplugged (i.e., at their vector connection point, etc) from the MSF. The ACM is typically supplied with cables, such that one or more or all of the VWM's, TWS, etc. can be plugged into the ACM or it's cables such as to allow the temporary or otherwise control of the VWMs, TWS, etc. Typically, it will only be the data and control cables which will be provided and/or used by the ACM. That is, the ACM may only provide means of supplying minimal or no electrical power to the VWMs or TWS, etc.

Typically, when the vehicle is under the control of the ACM, its speed will be limited to some relatively slow value. The ACM will typically contain a vector control computer capable of at least running a typically minimal version of the vector control software capable of, with the typically minimal controls on the ACM allow the vehicle, to be operated or tested within the speed or other constraints which may be imposed on the ACM operation of a vehicle.

15. Zero Infrared Signature Vehicle (ZIS) or Infrared Camouflage.

Due to the high energy efficiency of this technology, it provides the optimum ability to construct vehicles with a zero or near zero infrared signature.

In one form of the invention, a thermal mass with significant thermal inertia, such as eutectic salt or ice or liquid hydrogen or nitrogen or oxygen etc is contained within the vehicle, such that a network of pipes carrying a liquid or gas, under software / computer control can hold the temperature of the external surfaces of the vehicle and including its VWM's of other wheel assemblies, substantially at the temperature of the surroundings.

The network of pipes carrying a liquid or gas which will be cycled around the external surface of the vehicle and the VWM's etc, and then pass via a heat exchanger to sink the heat into the low temperature thermal mass, under the control of the software based temperature control system which would include one or more typically infrared, non contact temperature sensors, which would continually monitor the temperature of objects external to the vehicle, and "in front" of the vehicle such that a closed loop, software based temperature control system can maintain the temperature of the infrared emission from the vehicle as close as possible to the temperature of the infrared emissions from the surrounding terrain. Typically the network of pipes may be in a star configuration, with one or more pipes being provided for each part of the external surface etc, such that its temperature can be controlled by its own closed loop software based temperature controller, with its own temperature sensors on that part with the external or other surfaces. Additionally the pipe (or pipes) feeding the

part may contain their own flow control devices or valves such as to regulate the flow of the liquid or gases such as to control the temperature of that part.

Hence the temperature control system may contain many closed loop systems, each regulating the temperature of one or more parts. Typically all of these systems will use the one "master reference" which would specify the temperature at which the parts etc of the vehicle are to be maintained at.

The thermal mass into which the heat energy is sunk, would typically be of such size as to allow the temperature of the vehicle to be held at the required level for a period of at least minutes and more typically for hours, under typically night time conditions. Typically once the ability of the thermal mass to sink thermal energy at the required temperature was nearly expended or otherwise, the vehicle would return to base, or some appropriate location where the temperature of the mass could be lowered, either by conventional refrigerator means or via chemical refrigeration means.

Alternatively, where the ice or liquid hydrogen or nitrogen or liquid oxygen etc may have been expended, it could be replaced by conventional means.

In one form the thermal mass or media, may be contained within a canister or module or tank, of design, such that it could be quickly exchanged with another at the correct temperature such as to allow the vehicle to return to its ZIS mode, and hence return to service. This would allow the vehicle to quickly discard the thermal mass, should that be necessary.

In one form similar to the above, the ZIS vehicle would typically use starlight and or infrared vision equipment and GPS systems such as to allow it to "see" objects external to the vehicle, and navigate etc. Where conventional windows (translucent to light) where used, they would typically be of such designs as to be opaque to infrared, such that infrared emissions from personnel and equipment within the vehicle would not escape from the vehicle. Typically these would also be cooled, along with other external surfaces of the vehicle.

In the above forms of the vehicle when they were operational, typically they would use the polyphase traction motors within the VWM's etc to cause the vehicle to move as required. Typically all equipment within the vehicle would be electrically powered.

Additionally in the forms of the ZIS vehicle as described above, they may use storage batterys or "chemical batterys" etc as the source of electrical energy when operating in ZIS mode.

Typically these batterys being recharged by fuel cells etc, typically once ZIS mode operation was no longer required.

Alternatively some forms of the ZIS vehicle may contain a thermal mass or low temperature medium such as to allow the waste heat from the fuel cell etc to be sunk into the thermal mass or low temperature media.

In one form a battery pack may be modular and located beneath the vehicle or external to it or such that it can be released and at least temporarily discarded, typically by a release mechanism, which can be operated from within the vehicle.

This battery pack may also contain a radio or other beacon, which is activated some time (possibly hours or days later) such as to allow the retrieval of it at an opportune time.

This battery pack may also contain provision for it to be cooled, particularly when it is mounted in an exposed external surface of the vehicle.

In one form of the invention, similar to the above forms, the hydrogen gas released from the liquid hydrogen system of the above forms, may be used to power the fuel cell of the vehicle. These forms may also contain means of storing the hydrogen gas, i.e., pressure tanks, or other means including the use of a permeable medium. These may store it permanently or on a temporary basis, such as till the fuel cell is ready to use it.

16. Air-conditioning and cooling

In one form of the invention a thermal mass with significant thermal inertia, such as an eutectic salt, or ice or liquid hydrogen etc. may be provided. This may be used as a sink for heat, such as to allow for cooling of the air within the vehicle, or parts of the vehicle, or components such as batteries for example, which operate best at a low temperature.

This low temperature thermal mass or means may thus provide for some or all of the cooling of the vehicle, its air, its components etc. with a minimal requirement for electrical or other energy, as may otherwise have been required to power compressors or peltier effect devices etc.

Typically at some convenient time this low temperature (or otherwise) thermal mass or medium may be replaced, or again had its temperature lowered by external means, such as conventional refrigeration equipment etc.

17. Gyroscopic Stabilisation of Wheels' Direction of Steer

In one from of the invention, where the polyphase traction is mounted in a VWM, and the motor moves with the wheel as the angle of steer is changed, and if the major axis of the motor remains in a plane parallel (or essentially so) to the plane on which the vehicle rests.

In this form of the invention the polyphase traction motor may be designed and operated such (i.e. its moment of inertia and RPM) are such that under certain operation conditions (i.e. vehicle speed and/or gear ratios) that the polyphase traction motor is able to develop significant gyroscopic force such as to resist the (absolute) angle of steer being changed.

In this form of the invention this feature can assist as it tends to keep the (absolute) angle of steer constant. This can be of advantage when the vehicle is travelling on a straight road at significant speed - which is also one of the times when this gyroscopic force can be particularly significant.

Should the steering mechanism fail, it will tend to keep the vehicle travelling straight ahead. This can be of advantage as generally when a vehicle is travelling at speed on a road, it is significantly straight!

It allows for the possibility that the steering mechanism and its associated typically "computer means" control system can continually apply (small or other) steering forces to the wheel and by checking the deviation (or lack of deviation) of the wheel on a real time, continuing basis can thus ensure a high degree of confidence in the steering system.

One disadvantage of this form is that it should the vehicle skid, etc., i.e. when there is ice or oil etc,. on the road, then the gyroscopic force will tend to keep the wheels pointing in the original direction instead of in the direction of the skid, and as such may tend to hamper the vehicle and the operator as they attempt to regain control.

18. Gyroscopic Allowance in the Steering System

In one form of the invention where the polyphase traction motor is mounted in a VWM, and the motor moves with the wheel as the angle of steer is changed and if the major axis of the motor lies in a plane substantially parallel to that on which the vehicle rests. Then under certain conditions (partially when the motor's speed is high) gyroscopic forces may be experienced by the VWM's steering motor and its sensors and their associated typically "computer means" control systems.

This form of the invention contains a software/hardware mechanism such that a correction or allowance is provided such that the signal from the strain gauge (or other force sensors arranged so as to measure the steering torque) on the steering systems can be corrected such to provide a more accurate indication of the actual steering torque being exerted on a wheel, it is this “corrected steering torque” signal which is sent to the Control Software running in the MCC, the basic form is as follows:

Tcs = Tsensor – Tga

where

Tcs = The corrected steering torque
Tsensor = The torque indicated by the torque sensor etc
Tga = The gyroscopie allowance torque.

This has the advantage that the tactile feedback provided by the steering wheel to the operator can be a more accurate indication of the steering forces being experienced by the wheels as they interact with the road surface.

In one form of the invention as described above, the computer means calculates the force experienced (due to the gyroscopic action of the polyphase traction motor) from fundamentals such as its RPM and its moment of inertia.

In another form of the invention the "computer means" steering control system associated with the wheel can use a table (located in semiconductor or other memory) which contains pre-calculated or other values. Hence using the current RPM of the motor, the corresponding value of the correction can be found.

19. Preferred Inertial Loading of Wheels in a Vehicle During Braking

In one form of the invention the polyphase traction motor(s) are mounted such that the major axis of the polyphase traction motor(s) is significantly at right angles to the major axis of the vehicle and lying in a plane significantly parallel to the surface or which the vehicle is travelling.

Additionally, the direction of rotation of the traction motor(s) is arranged such that it is the opposite sense to that of the wheels, such that as the operator brakes the vehicle, and as the speed of rotation of the polyphase traction motor(s) is reduced (due to the action of regenerative, or mechanical brakes, etc.) that additional loading is applied to the rear wheels of the vehicle.

Note: in most vehicles, as the vehicle brakes a turning moment is generated due to the centre of gravity of the vehicle being above the plane of the road surface, such that weight is transferred from the rear wheels to the front wheels. Hence, as the vehicle brakes - and the weight on the rear wheels is reduced - that the tendancy of the rear wheels locking or exhibiting other detrimental behaviour increases.

This form of the invention has the advantage of increasing the force (at right angles to the road surface) between the rear wheels of the vehicle and the road surface during braking. Note that conventional wisdom is that during braking that it is the front wheels which are the most important. Generally however, if the weight on the rear wheels can be maintained, then additional braking force can be developed by the rear wheels, which tend to help prevent the vehicle going into a skid, etc.

20. Inertial Loading of Wheels in a Vehicle During Acceleration/Deceleration

In the form of the vehicle as described above, as the vehicle accelerates additional loading is applied to the front wheels.

This has the advantage of allowing better traction on the front wheels and thus ensuing better stability - i.e. reducing the tendency of a vehicle to flick around, etc.

Similarly, when braking, additional loading is applied to the rear wheels to reduce loss of traction.

22. "Neutral" Inertial Loading of Wheels During Braking and Acceleration

In one form of the invention similar to those described above, but with two or more polyphase traction motors, the major axis of which are significantly at right angles to the major axis of the vehicle and in a plane significantly parallel to the surface or which the vehicle is travelling. And in which the direction of rotation of the polyphase traction motors is arranged such that half (or substantially half) of the polyphase traction motors rotate in one direction and the other half in the other direction. In this form of the invention the power transmission between the motors which turn in one direction, and their

wheels, is different to the power transmission between the other direction motors and their wheels. The difference between those two versions of the power transmission is typically that one version may include one more (or less) external toothed gear, such that the direction of rotation of the polyphase traction motor associated with that power transmission can be opposite to what it would otherwise be.

In another form of the invention, substantially the same as the above one external toothed gear is replaced by an internal toothed gear, in one version such that the sense of rotation of its input and output shafts are opposite to what it otherwise would have been.

In another form of the invention substantially the same as above, two externally toothed gears are replaced by two pulleys and a belt, or two sprockets and a chain.

In another form of the invention with typically two or more polyphase traction motors, they are located with their major axes at right angles to the plane on which the vehicle is travelling, and typically looking down on the vehicle from above, half will be turning clockwise and half will be turning counterclockwise! Such that as they accelerate and decelerate, they will be loading neutral (at least as regards their rotational inertia).

In another form of the invention similar to above, where the major axes of the motors are at right angles to the plane on which the vehicle is travelling, that the polyphase traction motor driving the wheel or wheels on the left hand side of the vehicle will rotate counterclockwise (when looking down from above) to cause the vehicle to move forward. And similarly, these driving the wheels on the right hand side will rotate in a clockwise direction (when looking down from above) to cause the vehicle to move forward.

Hence, as the vehicle goes into a corner and the motor in the "outside" speeds up and/or the motor on the "inside" slows down then a turning force of the correct sense will be exerted on the chassis of the vehicle (by the accelerator / deceleration of the motors), such as to assist it to turn in the required direction. Additionally, when the vehicle is accelerating or decelerating in a straight line, no "net" turning force is produced on the vehicle, (by the moment of inertia of the motors) as both motors accelerate or both motors decelerate.

ON AXIS WHEEL PIVOT (AWP)

Reference to drawings associated with this patent will shown that in most cases wheel which are steered (i.e., pivot) do so about the minor vertical axis of the wheel. Hence typically the forces due to the tractive effort of the wheel lead to the generation of minimal torque about the pivot point for the wheel.

In one form of this invention which contains a steerable wheel, then the axis of the pivot point (about which the wheel pivots as it is steered) is typically coincident with the vertical minor axis of the wheel.

VERSATILITY OF THE EZE SYSTEM

Another demonstration of the versatility of the VWM's or wheel assemblies is in helicopters. Where they will allow helicopters freedom of movement on the ground similar to that when airbourne, particularly where the blades of the helicopter can be furled or otherwise folded to reduce their size. Additionally because the wheel motors and their batteries (being on the underside of the helicopter) help to lower the centre of gravity which is, of particular importance during lift off and landing. Note that typically the batteries will be charged while the helicopter is airborne.

One other application is that of tractors and ride of mowers, which are specifically designed and built for mowing grass, etc. Typically they contain an internal combustion engine located in the main structural frame, which is coupled via a rather long and massive power transmission, including flexible joints etc, to the cutting blades which are located in a mechanism which can be raised and lowered, relative to the MSF. Also note that the majority of the power developed by the engine is used to drive the cutting blades only a significantly smaller part being used to drive the wheels.

These tractors / mowers in future may locate the engine on the mechanism which contains the cutting blades, such that the drive mechanism to the blades is short, and does not need any flexible joints, because the engine now moves up and down as you raise and lower the mechanism on which the cutting blades are located. Additionally only a few flexible cables are needed, i.e. to feed electricity from an alternator on the engine to the VWM's or wheel assemblies. Also when not cutting grass you will be able to drive it around using the energy stored in the batteries in the VWM's or wheel assemblies, and not even start the engine, alternatively the engine may be running and the blades disengaged.

Another implementation may use the modular wheel assembles (VWM) with its suspension as described earlier, such that the cutting blades and the engine can be all located on the main structural frame which can now be raised or lowered, on the suspension.

BRIEF DESCRIPTION OF THE DRAWINGS

Embodiments of the invention will be described with reference to the following drawings in which

Figures 1A to 1B illustrate two mechanical steering linkages with selective over ride.

Figures 2A to 2I illustrate in more detail the operation of parts of a selective steering override mechanism.

Figures 3A to 3H illustrate a wheel module which could be of benefit on earth moving equipment, etc.

Figure 4A and 4B illustrates a vector wheel module, with a suspension, referred to here as twin axial.

Figure 5 illustrates another vector wheel module similar to Figures 4A and 4B.

Figure 6A and 6B illustrates another version this time with a coaxial suspension.

Figure 7A to 7D illustrates the geometry of a vehicles wheels when in cruise mode.

Figure 8A to 8J illustrate a cruise crab control and a pseudo gear change control.

Figure 9 illustrates the electronic and computer circuitry used in a typical vector wheel module.

Figure 10 illustrates the electronic and computer circuitry used in a typical EZE vehicle.

Figure 11 illustrates a vector wheel module with low unsprung weight.

Figure 12 illustrates another vector wheel module similar to that of Figure 11.

Figure 13 illustrates another vector wheel module similar to Figure 11.

Figure 14A and 14B illustrates a vector wheel module with good ground clearance.

Figure 15 illustrates a vector wheel module similar to that of 14A and 14B but with lower unsprung weight.

Figure 16 shows a hub assembly with provision for an electronic gear change.

Figure 17 shows hub assembly similar to Figure 16, but provides for higher ratios between the two positions.

Figures 18A to 18G illustrate various modes of operation of vehicle with an arm suspension VWM.

Figures 19A to 19E illustrate a VWM with arm type suspension, mounting on a pivot with horizontal axis.

Figures 20A to 20G illustrate a VWM with arm type suspension, mounting on a pivot with vertical axis.

Figures 21A and 21B illustrate a VWM located within a grass cutting assembly.

Figures 22A and 22B illustrate grass cutting vehicles using the wheel within a cutter type arrangement.

Figures 23A and 23B illustrate a wheel motor assembly.

BEST MODE

Figures 1A and 1B illustrate two versions of a mechanical steering linkage with selective over ride which can over ride the computer controlled steering.

Referring to Figures 1A and 1B, there is illustrated in side section view a wheel assembly 10 where the steering of the wheel can be done mechanically should for instance the steering motor fail. Referring to the figures, wheel assembly 10 again has an internal drive motor (not shown) and an internal energy storage device such as ultracapacitor or supercapacitor etc (not shown). The ground wheel 12 of assembly 10 is rotatably attached relative to a axial member 11 which has an inverted T-shape configuration such that cooling air 13 can pass into the interior of member 11 for cooling. Member 11 is attached to the body 14 of wheel assembly 10 via main bearings 15 which allows wheel 12 to turn or pivot. The body 14 is formed from metal structural members which are attached to the vehicle suspension arms 16.

Rigidly attached to the T-shaped portion of member 11 is a bevel gear 17. Rotation of bevel gear 17 causes member 11 to pivot which in turn steers wheel 12. Bevel gear 17 is rotated by a intermeshing smaller bevel gear 18. Bevel gear 18 is attached to a shaft 19 which terminates in a large circular circumferentially toothed gear 20. Gear 20 is rotated by an electric motor 1 which has an output cog 2 which meshes with the circumferential teeth on gear 20.

Thus, activation of motor 1 to rotate its gear 2 will in turn rotate gear 20 either clockwise or anticlockwise as is desired. Rotation of gear 20 rotates shaft 19 which rotates bevel gear 18 which in turn rotates bevel gear 17 which, because of its rigid attachment to plate 11, causes plate 11 to turn which in turn steers wheel 12.

The arrangement in Figures 1A and 1B have a mechanical override whereby the wheels can be steered mechanically if desired. For instance, should motor 1 fail, it may be necessary to have a mechanical override mechanism such as shown here, to some form of direct mechanical steering linkage.

In Figures 1A and 1B, this is achieved by a second shaft 3 one end of which is attached to a pulley or like member 4 which forms part of the mechanical steerage linkage further details of which are not illustrated. Shaft 3 terminates in a steel plate 5 which locates within large gear 20. Plate 5 has a cut-out section in it in which one end of pawl 6 can locate. Also note that pawl 6 passes through a cut out in gear 20 to cam follower 7. Also that the cut in gear 20 is such that cam follower 7 can move towards (or away from) the axis of shaft 19 and 3 as the cam follower 7 follows cam 8, which is solidly attached to the body 14.

Pawl 6 is normally located within the cut out in plate 5 when angles of steer are small (as may be common when the vehicle is travelling at speed on a highway). Additionally note that even when the pawl 6 is located within the cut out in plate 5, that pawl 6 and plate 5 are normally not in contact with each other due to the cut out section in plate 5 being wider than the width of pawl 6. Hence, there is still some limited degree of freedom (possibly only 1° or 2° or less) under these conditions.

The movement of pawl 6 is controlled by a cam follower 7 as it follows cam 8. Hence pawl 6 is controlled so as to selectively locate within the cut out in the plate 5. That is the pawl locates within plate 5 when the angular displacement of gear 20 and plate 5 $\Delta\phi$ is less than some specified value.

Note that generally gear 20 and plate 5 normally turn in unison (or approximately so).

Additionally the shape of cam 8, in conjunction with the ratio of gears 17 and 18 can be such that the value of $\Delta\varnothing$ required for the location of pawl 6 within the cut-out in plate 5 is some function of the angle of steer of member 13, and hence wheel 12.

Hence, the shape of cam 8 and gear ratio 17 to 18 can be specified such that with small angles of steer (which may typically occur at high speed), that pawl 6 is always located within the cut out in plate 5, thus providing the ability of plate 5 (which is connected to the mechanical steering linkage via pulley 4) overriding the computer controlled "steer by wire" feature as provided via motor 1 and gear 2

which engages with gear 20. Hence, the parts as detailed above may provide a steering override mechanism (SOM).

Additionally when the angles of steer is large as may typically occur when manoeuvring in car parks etc (where typically speeds are low), that pawl 6 is not located within plate 5, and hence full advantage can be taken of the steer by wire feature.

Hence due to the use of a steering override mechanism as per Figures 1A and 1B, tight control of the angle of steer can be provided when the angle of steer is low (typically at high speed). Also when angles of steer are large, so is the degree of freedom, such that full advantage can be taken of the software controlled "steerby wire".

Also note that the SOM of Figure 1A has some additional advantages, due to the pitch circle diameter of gear 18 being one fourth that of gear 17. Firstly this does act to reduce the torque experienced by the principal SOM components, i.e., shaft 3, plate 5, gear 20, pawl 6, etc. Additionally, the four to one reduction ratio means that the difference in width between pawl 6 and the cut out in plate 5 can be four times greater (for the same degree of freedom) than that of Figure 1B, hence it is possible to achieve greater accuracy, in specifying the degree of freedom when pawl 6 is located within the cut out in plate 5.

Additionally due to the 4:1 reduction ratio, the selective SOM characteristic will repeat every 90° of the wheel 12. Hence the SOM of Figure 1A will provide it SOM characteristic when the vehicle is travelling straight ahead, and also when travelling at 90°, also at 180° and 270°.

In another embodiment (not shown) a reduction ratio of one half may be used which will provide a selective SOM characteristic every 180°, i.e., straight ahead and reverse.

Figures 2A to 2I, illustrate in more detail the action of the SOM mechanism.

Referring initially to Figures 2A to 2C, these slow the wheel in a straight ahead position, i.e. Figure 2A shows cam follower 7 in its mid or centre position on cam 8. Hence in Figure 2C we see pawl 6 engaged in plate 5, such that the plate 5 and pawl 6 are forced to move in unison.

Next refer to Figures 2D to 2F, these show the operation when the steering wheel is displaced from straight ahead position, but the degree of freedom to the "steer by wire" is still restricted, i.e. Figure 2E shows cam follower 7 still in a position on cam 8 such that pawl 6 is still engaged in plate 5 as shown in Figure 2F.

Next refer to Figures 2G to 2I, these show the position of the som components when it is in its "low speed" condition where the "steer by wire" feature has unrestricted freedom to steer the wheel, i.e. Figure 2H shows cam follower 7 in such a position on cam 8 that it has moved pawl 6, such that it is not engaged in wheel 5.

Hence Figure 2I shows that component 24 is now not restricted in its freedom of movement by plate 5.

Figures 3A to 3H illustrates one form of a vector wheel assembly with low unsprung weight, and 360° of freedom and suitable for general use across a wide range of applications. One particular option shown on this form is the steering lock, particularly suitable for applications like earth moving equipment in that this from of the steering lock using hydraulically operated callipers applying force to friction pads which lock to a disk, allows for rapid locking and unlocking of the steering lock mechanisms.

Reference to Figure 3G shows how direct current is provided to the vector wheel module via the vector connection point's plug/socket assembly 40 which charges batterys and or ultracapacitors 41 and generally supplys electrical power to the VWM, and in particular to the polyphase inverter / controller 42, which supplys the polyphase current waveforms to the polyphase traction motor 43 such as to cause it to turn. Reference to figure 3F shows that motor 43 also turns the small pulley 44 which is rigidly attached to its shaft. The small pulley 44 causes the belt 45 to move which forces the larger pulley 46 to rotate and hence the shaft 47 which rotates in bearings 48 and 49, and causes the small gear 50 to rotate, which in turn forces the large gear 51 to rotate which is rigidly attached to shaft 52 which runs in wheel bearings 53. Shaft 52 is rigidly attached to the hub 54, such as to cause it to also rotate. The hub 54 is attached via wheel nuts and bolts 55 to the wheel 56.

Also the vector control software running in the Motion Control Computer send commands via the data communication network to the vector connection point 40 shown in Figure 3G. These pass to the slave control computer 60, which in turn sends commands to the polyphase inverter / controller 42 such as to cause it to output the correct current waveforms to the polyphase traction motor 43.

The chassis is mechanically attached by bolts 61 to the stationary part of the VWM's frame 62, which bears on the main pivot bearings 63 which allow the VWM's pivoting frame 64 to pivot under the control of the dual steering motors 65 which are also controlled by the slave control computer 60. The pivoting frame 64 is rigidly attached to the polyphase traction motor 43 by bolts 66.

Reference to Figure 3F shows the polyphase traction motor 43 pivots in bearings 67 and 72 at either end of the swinging arm 68 which pivots in bearings 70 and 71, on the gear box housing 76.

Hence as the load carried by this VWM changes, the swinging arm 68 pivots on bearings 70 and 71, also the suspension 75 shown in Figure 3C compresses and expands.

Reference to Figure 3G shows that some of the vehicles weight is carried by 62 the stationary part of the VWM, which transfers this weight via the pivot bearings 63 to the pivoting frame of the VWM 64. Part of this weight is carried by the suspension items 75 (spring and shock absorbers etc) the bottom end of which rest on the arm 76 which transfers that part of the weight to the gear box housing 76, as shown in Figure 3C.

The other part of the weight is carried via the VWM's pivoting frame 64 to the polyphase traction motor 42 and then via the bearings 67 and 72 to the swinging arm which transfers the weight via bearings 70 and 71 to the gear box housing 76, i.e. both parts of the weight end up being carried by

the gear box housing 76 which is carried by the wheel bearing 53, which are carried by the shaft 52 which is carried by the hub 54, which is attached via wheel nuts and bolts 55 to the wheel 56 which rests on the ground.

Reference to Figure 3E shows sensor 57 which measures the height of the suspension. The output signal from sensor 57 passes to slave control computer 60, which typically send it via vector connection point 40 to the main control computer.

Figure 4B illustrates another version referred to here as a twin axial suspension with low unsprung weight similar to Figure 3. Here the polyphase traction motor 94 turns its shaft 95 and hence the belt 98, which turns pulley 100, which is rigidly attached to pulley 101 which is also forced to turn, and hence belt 102 such that pulley 103 also turns which in this form is rigidly attached to 104 the input shaft of a combination planetary gear box and hub which are commercially available and are sometimes referred to as power hub assembly 105. The power hub assembly 105 may have one or more stages of planetary (or other gears) within it, depending on the ratio required for a particular application. The output shaft 110 of the power hub 105 (which is typically at a lower RPM than the input shaft 104), is rigidly attached to center 116 which has provision for wheel mounting nuts and bolts 107 which are used to attach the wheel 106.

Bearings 97 run on a protrusion of the motor housing 94 such that arm 98 can move about the motor shaft 95. Arm 98 has bearings 111 at its other end which run on shaft 112 which runs in bearing 115 at its other end. Rigidly attached to shaft 112 are pulleys 100 and 101. The shaft 112 runs in bearing 115 in arm 113 which has bearings 114 at its other end which run on a protrusion from the power hub assembly 105, such that arm 113 can move axially about the input shaft 104 of the power hub assembly 105.

Arm 98, shaft 112 and arm 113 allow the wheel 108 and the power hub assembly 105 etc to move relative to the motor 94 and its mounting bracket 109 which attaches it to the yoke 117 which is pivotally attached via bearings 118 to the stationary frame 119 of the VWM.

Some of the vehicles weight rests on the stationery frame 119 of the VWM as shown in Figure 4A, which transfers it via bearings 118 to the yoke 117 which transfers it via springs 122 and 125 and shock absorbers 128 and 127 to the lower member 130 which is attached to the stationery part 131 of the power hub assembly 105 and hence via the power hub assembly to the wheel nuts and bolts 107 and then to the wheel 108 which rest on the ground or other surface.

The yoke 117 is constrained to move in the plane, in which axial members 121 and 126 lie, as the yoke 117 slides on these axial members 121 and 126. The lower ends of axial members 121 and 126 are rigidly attached to the lower member 130.

Figure 5 illustrates another version similar to that of Figure 4A and 4B.

Here the motor 140 drives its shaft 146 to which pulley 145 is rigidly attached, which drives belt 147 which drives pulley 148 which is rigidly attached to shaft 144, which drives small gear 152 which

it is also rigidly attached to shaft 144. Small gear 152 drives larger gear 153 which is rigidly attached to shaft 154 which is rigidly attached to the hub plate 157 such that it causes it to move. Wheel nuts and bolts 158 attach the wheel 159 which is hence cause to rotate.

Again note that arm 142 is able to rotate on bearings 141 on a protrusion 161 from the motor housing, such that the arm 142 can move axially about the motor shaft 146.

A bearing or other mechanism 160 is located in arm 142 such as to allow its ends to pivot relative to each other etc. The other end of arm 142 runs on the bearing 143 and hence is restrained to movement about the axis of shaft 144, which rotates in bearings 143 and 150.

Shaft 154 rotates in the wheel bearings 155.

The gear box housing 151 is able to move about the axis of shaft 154 due to the bearings 156 which run in the lower member 162 to which are rigidly attached the axial members 163 and 164 on which the yoke (not shown) slides.

In another form (not illustrated) the belt and pulleys of Figure 5 are replaced by two gears.

Figure 6A illustrates a VWM of different construction, and is referred to here as a coaxial suspension. Also note that Figure 6B illustrates an example of the use of a ratio change mechanism.

Refer to Figure 6B, here the traction motors torque is transferred to spline 201 which runs in the composite gear which consists of a larger gear 202 and a smaller gear 203, all of which is forced to rotate due to the rotation of the spline. With the ratio change mechanism in the position as illustrated, as the small gear 203 rotates, it forces gear 221 also to rotate, which being rigidly attached to shaft 214 it also causes gear 213 to rotate due to it also being rigidly attached to shaft 214. As gear 213 rotates, it forces gear 215 to rotate and hence the shaft 216 to which it is rigidly attached. Gear 215 being rigidly attached to shaft 216 causes it to rotate which causes the hub assembly 225, to rotate and hence the wheel (not shown) which is attached by the wheel bolts 218.

This form also includes an electrically operated ratio change mechanism. When motor 211, for example, rotates in a clockwise direction, it will cause the lead screw 209 to also rotate which, due to the thread in the nut-yoke 212, will cause it to move downwards such that first of all gear 203 will disengage from gear 221, then as motor 211 continues to rotate clockwise, that gear 202 will then engage with gear 222 such that now the ratio of the power transmission between the spline 201, and the wheel (not shown) is changed. Also as the composite gear 202, 203 moves the electronical characteristics of sensors 204 and 208 will change such that electronic and computer means associated with these sensors will be able to verify the position of composite gear 202, 203, and hence the gear ratio.

Figure 6B also illustrates the use of a disc brake mechanism similar in some respects to a conventional one.

When the brake callipers 219 are actuated (by hydraulic or electric means), they close on the disc 217 and due to the friction between them, tend to apply a force such as to slow the rotation of the

hub assembly 225. When this happens, the strain gauge 220, on which the callipers 219 mount, experiences the force due braking, the other side of the strain gauge 220 being attached to the gear box housing 210. The strain gauge, when subjected to a force, changes its electrical characteristic such that signal from the strain gauge (or similar) 220 allow electronic and computer means to calculate both the magnitude and sign of the force, and hence the torque that callipers 219 are exerting on the disc 217 such as to slow or stop it.

Reference to Figure 6A shows strain gauge 198 on which motor 188 (and its polyphase inverter 199) mount. As a result, electronic and computer means associated with strain gauge 198 can calculate the magnitude, and sign of the force, and hence the torque which motor 188 is experiencing, both as it accelerates the vehicle, and also during regenerative braking where motor 188 acts as an alternator to provide electrical energy to battery and or ultracapacitor 189.

Not illustrated is a steering angle sensor which senses the position of frame 181, such that by electronic and computer means, the angle of steer of the wheel can be calculated.

The wheel 180 pivots (due to the action of steering motor 185) about a line, which is on or close to the vertical minor axis of wheel 180. As a result the tractive effort of wheel 180 does not place a loading on the steering mechanism consisting of steering motor 185.

The angle of steer is changed by motor 185 rotating such as to cause the pivoting part of the VWM 181 to pivot on bearings 182.

Note that the steering motor 185 (typically a poloyphase axial flux brushless dc motor) is mounted on strain gauge assembly 186.

Hence, electronic and computer means associated with strain gauge 186 can calculate the magnitude and sign of the steering torque. Details of the steering torque are passed to the vector control software which uses this information for a number of things, and in particular to control the tactile feedback applied to the operator's steering wheel.

Figure 7A illustrates an example of a vehicle travelling around a curve, a small part of that curve is being treated here as an arc of a circle.

The vehicle 277 shown in Figure 7A has four wheels 251, 258, 265, 275 arranged in a regular pattern similar to that of a conventional vehicle. Consider this, vehicle 277 is travelling forward, its front 253 being shown at the top of the page and if we look at wheel 251, we see that a minor axis 279 of the wheel 251 is at right angles to a radius 262 which intersects the vehicles minor axis 263 at a point 260 which, in the invention, is the centre of the circle of which this vehicle 277 is travelling an arc. In the method of the invention, wheel 251 is forced to steer at angle 252 (to the major axis 254).

Angle 252, being the angle between the tangent 279 of the arc 278 of radius 262, and whose centre is point 260.

The distance of point 260 from the vector datum point 280 is distance 263 which is elsewhere calculated in the invention and referred to as Rc.

Similarly, wheel 258 has a minor axis 256 which is tangential to arc 257 of radius 259, the centre of which is 260.

Similarly for wheel 265.

Similarly for wheel 275.

Reference to Figure 7B shows a vehicle in cruise mode similar to that shown in Figure 7A, except that now the centre of the circle 281 about which the vehicle is turning is located on the left hand side of the vehicle. The vehicle shown in cruise mode in Figure 7B is vector wheel modules 284, 285, 286, 287 which have a significant degree of steering freedom. Figure 7B shows the vehicle turning with the radius to the centre of the circle being significantly greater than 50 percent of the vehicles width. Note centre of circle is the point 281.

Reference to Figure 7C shows the vehicle still in cruise mode with the radius to centre of circle approximately equal to 50 percent of the vehicle's width. Note the centre of the circle about which the vehicle is turning is point 282.

Reference to Figure 7D shows the same vehicle as above, still in cruise mode, but now with zero radius to centre of circle, about which the vehicle is turning. This results in what is referred to here as spin on a spot ability. Note the centre of the circle is point 283.

Figure 8A illustrates a possible position of a cruise/crab control 300 in vehicle whose front 301 is near the top of the page the vehicle having a major axis 302 and a minor axis 308, a left side 311, and a right side 309, and a rear end 310.

The knob 304 is at the centre of the cruise/crab control 300, and protruding from it in a forward direction is button 315 on which is a representation 314 of some object such as an arrow etc. which, in Figure 8A, is visible. Similarly, a button 306 is facing rear from the knob 304 and it also has a similar marking 312. Buttons 315, 312 are referred to as the cruise buttons and when protruding, as shown in Figure 8A, are meant to imply that the vehicle is in a mode where it is capable of moving in a direction similar to that of major axis 302.

Buttons 305, 313 are obscured which is meant to imply that movement in a direction similar to that of a minor axis 308 is not possible.

Also, no markings are visible on buttons 305, 313. Again, this is meant to imply that movement in a direction similar to that of the minor axis 308 is not possible.

The cruise/crab control 300 has three positions. Firstly, it has a central position as shown which is mid-way between a marking 303 (which may contain the word "forward"), and another marking 307 (which may contain the word "reverse"). This mid-way position causes the command of signals to each VWM to disable the polyphase traction motors, and to apply the parking brakes etc.

When the cruise/crab control 300 is moved towards the marking 303, it sets the command signals to each VWM such as to move forward. Similarly, when the cruise/crab control is moved

towards the marking 307, it sets the command signals to each VWM such as to move in a reverse direction.

When the buttons are in a state as shown, a signal from a sensor (not shown) in the cruise/crab control 300 is sent to the vector control software to command it to control the VWMs such that the vehicle can move in a cruise mode.

Figure 8B shows the cruise/crab control 326 in its crab position, i.e. representations of a crab 320 and 324 are visible, on the crab buttons 323 and 327 which are located on the right and left side of the cruise/crab control 326.

The cruise buttons 322 and 325 have been pressed in such that any logo, marking etc. on them is now obscured.

When the buttons are in the state as shown, a signal from a sensor (not shown) in the cruise/crab control 326 is sent to the vector control software to command it to control the VWM's such that the vehicle can move in crab mode, or at least it can do that once the speed etc. of the vehicle has slowed sufficiently.

Figure 8C shows one implementation of the cruise/crab control 330 in its cruise position with the buttons on the major axis 331 exposed, and crab buttons obscured. Figure 8D shows a side elevation of 8C. Figure 8E shows the cruise/crab control 332 in crab mode with buttons along the minor axis 333 exposed, and the cruise buttons obscured. Figure 8F shows a side elevation of 8E. Figure 8G shows another elevation of the cruise/crab control 335.

Reference to Figures 8H, I and J shows a tight lose control (TCL) which acts as a pseudo gear change control. Note that the cruise crab control, i.e. item 335 of Figure 8G, may form part of the TCL control of Figures 8H, I and J. In this combined form with one hand the operator would be able to select between cruise and crab mode, forward, neutral and reverse, as well as the pseudo gear change features.

Reference to Figures 8H and 8I shows the click mechanism which consists of ball 342 and spring 341, which move across indentations 337 and 340.

Reference to Figure 8I shows the rotary position sensor 345 which may be a potentiometer or hall effect, or opto type. Reference to figure 8J shows the knob 338 in its neutral position, as shown by the lettering 348. The knob 338 may be moved to one or more "forward" positions as indicated by the arrows 349, the size of which increase such as to indicate the higher speed. Similarly other graphical symbols may be used for 349 such as a line of increasing width or dots, etc. similarly one or more "reverse" positions are shown as 347.

Figure 9 shows a schematic representation of the various electrical, electronic and computer means within a typical VWM and the interconnections between them.

The Vector Control Computer (VCC) 350 is shown with its various input pins, an example of which is 351 which has the commands arriving from the master motion control software which runs in

the master motion control computer (MCC) (not shown) in the vehicle. Similarly an example of an output signal from the Vector Control Computer (VCC) 350 is the status line 352 going from the VCC 350 again to the master motion control software which runs in the MCC. Output signal 353 takes command and control signals to the polyphase inverter controller associated with steering motor 405. Input signal 354 provide the angle of steer from the steering angle sensor 406.

Output signal 355 controls field effect transistor 417 and its associated components such as to dump energy in Resistor 416, when the energy dump braking technique is activated.

Input signal 356 is from the sensor 413 which monitors the dc current being sunk (or sourced) by the polyphase traction motor 415. Input signal 357 is from the strain gauge sensor 407 on which the steering motor mounts. Output signal 358 contains the RPM control and other data and commands to the polyphase inverter controller 414 associated with the polyphase traction motor 415.

Input signal 359 brings the status and other data from the polyphase inverter controller 414, regarding such parameters as its temperature, etc.

Input signal 360 brings the status of the polyphase motor 415, i.e. details such as its temperature etc.

Input signal 361 is from the strain gauge sensor 419, and provides details of the force that is being experienced, and hence torque, that the polyphase traction motor 415 is exerting

Input signal 362 is from the motor RPM (typically also direction and phase) sensor 418.

Output signal 363 controls the force which is being applied by the disc brake assembly 420 on to its disc such as to slow the vehicle. Input signal 364 from strain gauge 421 provides details of the retarding force (and hence torque) generated by disc brake assembly 420, which mounts on strain gauge sensor 421.

Input signal 365 provides details of the oil temperature within the gearbox (not shown) as provided by the temperature sensor 422.

Input signal 366 provides details of the oil level within the gearbox (not shown) as provided by the oil level sensor 423.

Input signal 367 provides details regarding the engagement (or otherwise) of the high ratio gear (not shown) as provided by the gear position sensor 424.

Input signal 368 provides details, regarding the engagement (or otherwise) of the low ratio gear (not shown) as provided by the gear position sensor 425.

Output signal 369 controls the gear position motor 426 which moves the gears (not shown) such as to provide the reduction ratio required.

Input signal 370 provides details of the vertical acceleration of the wheel within the VWM as provided by the accelerometer 427. Input signal 371 provides details of the height of the suspension (not shown) within the VWM as provided by the suspension height sensor 428.

Wire 372 provides the zero volt connection for the slave control computer 350, the other end of wire 372 being connected to the zero volt end of energy storage device (i.e. ultracapacitor or battery) 411, or via filters and other means (not shown) to the zero volt end of energy storage device 411, it acts as the direct current etc. return path. Input wire 374 provides the direct current feed path from the positive end of energy storage device 411, or via filters, regulators, fuses etc. which are not shown. Wire 373 provides details of the voltage applied to motor 415, such that the VCC 350 can enable the current dump 417 etc.

Electrical conductor 381 provides the zero volt connection from the vector connector point connection 402, and acts as the direct current return path for typically all electrical, electronic and computer means within the VWM. It is important to note, that typically the zero volt conductor may not be connected to the chassis of the vehicle or the frame of the VWM, or at least not in the first instance. The other end of conductor 381 connects to the negative (or zero volt) side of an arrangement of electrical interference filters, i.e. EMC filters 401 of which the multistage lossy transmission Line (MTL) described in the invention is an example.

Electrical conductor 382 connects the negative (or OV side) of the EMC filter 401 to the zero volt side of the energy storage device 411 such as to complete a return path for the direct current provided to the VWM from the vehicle.

Electrical conductor 383 provides the positive voltage connection from the connector 402 to the fuse/circuit breaker 403 and via diode 408 (or other device and circuitry to achieve reverse current protection etc.) to the positive side of the EMC filter 401. It is this conductor which provides the path for the direct current feed to the VWM. Electrical conductor 385 provides the path for direct current feed to motor 415 as it passes via charge/power controller 412 and then via conductor 385 to the positive side of the energy storage device 411. Electrical conductor 385 also provides the path for direct current to pass from the positive terminal of energy storage device 411 via the fuse/circuit breaker 412 to the input side of current monitor 413 or vice versa, depending on whether the polyphase traction motor 415 and its polyphase inverter/controller 414 is acting as a sink or source of electrical energy. Conductor 385 also connects to the positive side of the current dump resistor 416. Electrical conductor 386 provides the zero volt connection from the zero volt side of the energy storage device 411 to the zero volt side of the current dump assembly 417 and the zero volt side of the polyphase inverter/controller 414 and its associated polyphase traction motor 415. Electrical conductor 387 provides a path for the electrical bonding of the frame 400 of the VWM to the main structural frame of the vehicle via connector 402.

Figure 10 illustrates an example of the electrical and data etc. interconnections within a vehicle such as to provide for the use of the VWM's and other items as detailed in the invention.

Electrical conductor 455 is the positive conductor of the main power bus and provides a path for the distribution of electrical energy within the vehicle. It provides for the flow of electrical energy

from such sources as the fuel cell 525, which passes via a fuse/circuit breaker 524 and diode 523 (or other components and circuitry such as to prevent reverse current flow). Also from solar cells 533 via, controller 532 and fuse/circuit breaker 531 and reverse protection diode 530. Conductor 455 distributes the electrical energy to such items as the VWM's an example of which are the vector connection point connectors 451, 471, 521 and 537, via fuse/circuit breakers 452, 470, 522, 536.

Electrical conductor 456 provides the return path for the main power bus as described in he invention. It is referred to as the zero volt connection, and typically will not be connected to the chassis of the vehicle, in some cases it may be connected to the vehicles main structural frame, and typically be at only one point.

Output signal 454 passes from the master motion control (MMC) computer 480 to connector 451 with the commands to that VWM. Input signal 453 passes from connector 451 to the MCC computer 480 with the status from that VWM.

Similarly connections 472 and 473 to connector 471.

Similarly connections 518 and 519 to connector 521.

Similarly connections 534 and 535 to connector 537.

Electrical conductor 455 also feeds via diode 483 (to allow the computer to continue to operate should the voltage on 455 fall to zero) and then via charge controller 481 to battery (or supercap, etc) 482. A wire 484 from the positive side of the energy storage device 482 provides direct current to the Motion Control Computer (MCC) 480. Also wire 456 the 0 volt wire of the power bus connects to the negative side of 482 and also to the MCC 480 such as to provide a path from the return current.

A Global Positioning system receiver 458 connects via cable 456 to the MMC 480 so as to provide details of Latitude and Longitude. A tilt angle sensor 461 provides details of the vehicles divergence from the horizontal plane via cable 460.

The operator's display and control panel 462 connects via cable 463 to the MMC 480 so as to provide the required displays etc. and allow for controls, buttons etc. on 462 to control the MMC 480.

Antenna 464 feeds satelite or other radio frequency transceiver 465 which connects to the MMC 480 such as to allow remote control, or for remote status etc reporting.

The accelerometer 466 provides details of the vehicles acceleration along one or more axes to the MMC 480 via cable 467.

The accelerator pedal 506 position is sensored by its sensor 508 and the force applied to the accelerator by sensor 507 and provided to the MMC 480 via cable 509.

The position of the brake pedal 502 is provided by sensor 504, and passes via cable 501 to the MMC 480 as is also the signal from the brake force sensor 503.

The sign and magnitude of the torque applied to the steering wheel 492, as tactile feed back to the operation is controlled by steering simulation motor 495 under the control of the MMC 480 via the cable 500.

The sign and magnitude of the torque which is being controlled by the steering simulation motor 495 is sensed by strain gauge 496 and provided to the MMC 480 via cable 491. The status of the cruise crab buttons on the cruise/crab control 488 are provided to the MMC 480 via cable 486. The position of the cruise/crab control 488, i.e. forward, stop or reverse is also provided to the MMC 480 via cable 486, from its forward/stop/reverse sensor (not shown).

Where the VWM's have two or more ratios then the cruise/crab control may have a forward/forward slow/stop/reverse slow/reverse sensor (not shown) which will also feed via cable 486 to the MMC 480.

In Figure 11 shows a unit which could form the basis of a VWM or a single wheel assembly. Note that the steering mechanism is not show as is also the case for springs, shock absorbers and some other components.

This form of the invention is particularly suited to medium or heavier duty applications due to the large radial flux polyphase traction motor, the rotor 572 is hollow and rotates inside the stator 571.

The rotor 572 is rigidly connected to sun gear 574 such that it is caused to rotate which in turn rotates planet gears 599 and 575, both of which are free to rotate. Since internally toothed gear 576 is fixed, and since planet gear 575 is free to rotate on its shaft 578 which is rigidly connected to disk 579, hence disk 579, which runs on bearings 594, also rotates and hence spline 580 and its associated shaft and constant velocity joints (i.e. 582 etc) and hence spline 584 and wheel hub 585 to which is attached wheel 587 by the wheel nuts 588. Wheel hub 585 runs on bearings 589, which support it rotationally in bracket 590, the top end of which mounts in ball joint 591 such that it has a number of degrees of freedom. The arm which contains the ball joint 591, has its other end pivotally supported by pin 593. Similarly, the bottom end of bracket 590 mounts in a ball joint 592, the arm associated with which pivots on pin 594.

The pins 593 and 594 are rigidly attached to the main bracket 596 which is attached to the chassis 595 by nut 600.

Also mounting on the hub 585 is the rotor 562 of a disk brake assembly, the stator 561 of which is rigidly attached to bracket 590.

In Figure 11 the ball joints 591 and 592 and constant velocity joint 570 provide freedom of movement of the hub 585 and wheel 587 such that they can be steered by a steering linkage (not shown) or by a motor as shown elsewhere in this application.

In another embodiment (not shown) the hub 585 is replaced by a "Power Hub" (or similar) containing one or more stages of planetary reduction, such as to provide higher torque to the wheel.

In another embodiment (not shown) similar to that of Figure 11, but now the radial flux polyphase motor (ie items 596, 572, 573, etc) is replaced by an axial flux polyphase motor similar to that shown in Figure 12.

Figure 12 shows a form similar to that of Figure 11 except that now a axial flux polyphase motor is shown, consisting of housing 604, stator 605, and rotor 606, which runs in bearing 607. Also in this form the rotor 606 directly drives a constant velocity linkage 610 to the hub 613 and wheel 612. The housing 604 of the polyphase axial flux motor, mounts on the "chassis" 609. Typically, a linear actuator type steering mechanism similar to that as item in figure 14B, will be used for steering. Alternatively a traditional steering linkage may be used.

In another form (not shown) similar to that described above, which includes a linear actuator type steering system similar to that of Figure 14B, which would steer wheel 612, relative to the "chassis" 609. Now however, this form mounts the "chassis" 609 on a second steering mechanism similar to that of Figure 6A, i.e. consisting of items 181, bearing 182, steering motor 185 and strain gauge 186 of Figure 6A which mounts on the actual chassis 192 as shown in Figure 6A. Hence this form now has two steering mechanisms in series, that as shown in Figure 12 having a relatively small degree of freedom as limited by the ball joints 602 and 611 of Figure 12, and the linear actuator of Figure 14B. The other having extensive freedom as provided by the bearing 182 and steering motor 185 of Figure 6A.

There are a number of advantages of this system, for example, during higher speed operation where typically only small angles of steer are used, then the steering motor 185 of Figure 6A could be locked, and the linear actuator used, similar to that of Figure 14B. Now, however, if a fault was detected in the linear actuator system, then it could be locked, the steering motor similar to that shown in Figure 6A could be unlocked and used. Typically suitable warning etc, being displayed to the operator, to get the fault fixed.

Figure 13 illustrates a unit which is similar to Figure 11 except that wheel 629 can now only move vertically, relative to the "chassis" 625. This is due to the bracket 624 being mounted at its top end by a pin 621 on which top arm 622 pivots. The other end of top arm 622 pivots on pin 623 which mounts in the main bracket 626. Similarly, the bottom end of bracket 624 mounts on pin 630, which pivots in one end of bottom arm 628, the other end of which pivots on pin 627 which mounts in the main bracket 626 which is shown rigidly attached to the "chassis" 625. Hence Figure 13 illustrates a unit which may form part of an unsteered wheel on a vehicle.

Also if the "chassis" 625 mounts in one of the pivot mechanism as described in Figure 6A, then this figure 12 could in fact constitute part of a vector wheel module.

Figure 14A and 14B illustrate a unit suitable for heavier duty service, with good ground clearance. Now the upper arm 655 is above the wheel, and lower arm 662 is positioned considerably higher above the ground, thus giving good clearance. Motor 656 drives via planetary gear box 660, which drives the constant velocity linkage 659 and 652 feed through the hollow centre of motor 656 to gear box 666 and via its gears 650 and 665 to hub 667 and wheel 668.

In another implementation (not shown) similar to Figure 14A and 14B and where motor 656 would typically be an axial flux polyphase motor, the rotor of which connects directly to the constant velocity linkage consisting of 659 and 652. Hence it would not contain gearbox 660, and would be considerably more compact and lower cost.

Figure 15 shows a similar unit to Figure 14A and 14B. Now motor 694 drives via gears 692, 695, 696, 698 to constant velocity linkage 701, 702, 703 to a hub assy 706 and the wheel 708.

In a similar form hub assy 706 may consist of a power hub assy with an internal planetary gear box.

Figure 16 illustrates a hub assy with provision for a gear change. Input shaft 723 drives via spline 721 drives gear 720 which is shown engaged with gear 725 which is attached to the centre 726 to which the wheel is attached via bolts 727.

Ratio Change Motor 722 via lead screw and nut (not shown) can move gear 720 along spline 721 to engage with gear 724, which gives a different gear ratio, gear 724 also being attached to centre 726.

Figure 17 shows a hub similar to Figure 16. Here ratio change motor 737 drives via gears 738, 736, 735 to lead screw 739, which acts on nut assembly 734, which moves gear 732 on spline 731. Hence gear 732 may drive internal toothed gear 733 in one position or with gear 730 in its other position which drives gear 740.

Figure 18A illustrates a military vehicle such as an armoured personnel carrier which may be fitted with optional modules to provide amphibious operation, a long range fuel module, energy storage and/or cooling modules to provide infrared camouflage during night time operation, etc.

The vehicle of Figure 18A is shown fitted with four vector wheel modules which allow the wheels to be positioned for various modes, i.e. that of figure 18A, allows for very compact storage where the wheels such as 764 are retracted such that the vehicle can rest on its hull 766. Hence its height is a minimum, this is of advantage during transportation by marine vessels or by aircraft, etc. Also it allows high speed amphibious operation as water resistance is a minimum. As well, this mode makes it a simple matter to remove and replace one of the VWM's shown as consisting of main pivot 760, main arm 761, minor pivot 762, steering turntable 763, and wheel 764.

Figure 18B shows the vehicle still in a compact mode, but with sufficient ground clearance to allow it to drive out of a marine vessel during an amphibious landing. Note that the main arm 771 has pivoted on main pivot 770, yet turntable 773 and wheel 774 have retained their vertical attitude as per Figure 18A.

Figure 18C illustrates a mode suitable for fording a stream, or operating in a area where land mines may exist, i.e. because of the height of hull 786 above the ground there is a far greater chance of personnel within the vehicle surviving a land mine explosion.

Figure 18D illustrates another mode, suited to operation in an area where land mines may exist. Here the hull 796 is still high above the ground, but also the wheel 794 is now some distance out in

front of the vehicle, such that if a land mine was to be detonated by wheel 794, there is a good probability that the personnel within the vehicle will survive. This is further increased by the fact that the front surfaces 797 and 798 of such vehicles typically have the thickest armour. Also note that the hull 796 of this vehicle is of a V shape, which assists in reduction of blast damage, as it provides an easier path for the explosive gases to escape. Additionally, the chance of detonating a land mine is further reduced due to the ability of rear wheel 795 to exactly track wheel 794. This is due to the angle of steer of the wheels such as 794 being specified by its computer controlled turntable 793. Similarly, wheel 795 by its computer controlled turntable 799. All of these wheels angle of steer and speed being under the control a master motion control computer (not shown), which is located in the hull, and which uses algorithms such as those specified elsewhere in this application. Should the front wheel 794 detonate a mine, and be damaged, then the survival chances of the personnel in the vehicle, is further enhanced by the fact that the vehicle has a good chance of being able to rapidly exist what may be an ambush by changing its mode to that illustrated in Figure 18E. here the rear VWM 810, 811, 812, 813 has swung its wheel 813 forward such that the vehicle may still proceed even though VWM 800 is damaged. Due to a standard VWM being used in all locations on the vehicle, and a simple connection mechanism being used to attach the VWM's, hence semi-skilled personnel can quickly replace the damaged one, with a spare.

The mode illustrated in Figure 18D has another advantage, in that for example a amphibious module can be fitted or removed from the underside of the vehicle without the use of special lifting equipment due to the ability of the vehicle to change its height above the ground as illustrated in figure 18A to 18D. Further, the height and mode of the vehicle is also under the control of the master motion control computer (not shown) within the hull, such that it can change between the modes illustrated in figure 18D and 18E, without personnel needing to exit the vehicle, under what may be difficult circumstances.

Reference to Figure 18F shows a mode offering ease of access to the VWM, i.e. for inspection or changing a tyre, or for replacing a VWM without needing a jack, etc.

Reference to Figure 18G, shows one form of a VWM quick release mechanism, here tapered stub 814 (part of the VWM), engages with a matching taper 815 (part of the hull), such that it may be held in place by a single nut assembly 817. Hence to remove the VWM, first the electrical/data/fibre/cooling connector 816 is unplugged, next the nut is removed, such that the tapered stub 814 and hence its VWM can be removed.

Figure 18G also shows an explosive device 818, such as to unlock the taper, and to assist generally, particularly in the case where the VWM may be severely damaged, due to a land mine, etc, and needs to be removed quickly. Note that typically the tapered stub 814, may have a keyway and key (not shown) with a matching keyway in tapered section 815. Alternatively the tapers of 814 and 815

Figure 19E shows a section of the main arm 927. The cavity 920 allows cables etc from the hull to pass via the duct 928 through the main arm, then via the flexible coupling 939 to the wheel (not shown). The main pivot stub 921, approximately 270° of which is cut away to allow cables to pass through as discussed above. Bearing 922 mounts on a shoulder 929 of the main stub 921. The cylindrical section 923 of the main arm pivots on bearing 922, about the main pivot 921.

Height motor 931 drives bollard 932 such as to move rope 940, such as to move shafts 935 and 936 together or apart, such as to raise or lower the main arm 927. Note that as shafts 935 and 936 move together, that shafts 937 and 938 move apart, and vice versa.

In another implementation (not shown) a hydraulic rotary actuator (or slew motor) may be used to develop the turning moment about the main pivot (instead of the ropes and pulleys). This form would typically have its own hydraulic pump, driven by an electric motor, and also its own reservoir of hydraulic fluid all located within the VWM. This form may have a friction brake, or dog brake, or similar in parallel with the rotary actuator, such as to lock the main arm rotationally.

This form may have the arm mounted on the rotary actuator, with a certain degree of rotational freedom, and a torsion bar suspension or similar between the rotary actuator and the main arm.

Figure 20A illustrates another implementation of a VWM attached to a vehicle 970. Wheel 950 is attached via turntable etc 951 to the main arm 960 via minor pivot 952. Note the wheel assembly 950 and its turntable etc 951 may be similar to that illustrated in figure 19A, 19B, 19C. Main pivot 969 allows main arm 960 to pivot on the vertical shaft 959, which rotates in bearings 962 and 968 which are rigidly attached to enclosure 965. Disk 966 is rigidly attached to vertical shaft 959. Brake callipers 964 are rigidly attached to enclosure 965. Hence by locking callipers 964 on to disc 966, the vertical shaft 959 may be locked in a position about its vertical axis. Typically a "dog brake" (not shown) and or other means may additionally be used to rotationally lock vertical shaft 959.

Pivot 958 mounts one end of main hydraulic ram to vertical shaft 959. The other end of main hydraulic ram attaches via pivot 956 to main arm 960. Hence by pumping hydraulic fluid in and out of main ram 957, the main arm 960 can be raised or lowered, and hence the vehicle raised or lowered.

Pivot 955 mounts one end of attitude ram 954, the other end of which mounts via pivot 961 in the top end 953 of the turntable, etc, assembly 951. Hence by extending or retracting attitude ram 954, the attitude of the turntable 951 and wheel assembly 950 can be controlled.

Figure 20B illustrates the hydraulic, electric, electronic and computer control of a VWM such as that of Figure 20A. Attitude ram 975 and main ram 991 are located in the positions as shown in Figure 20A. All the other components of Figure 20B are typically located within the enclosure 965 of Figure 20A, note that the enclosure 965 will typically be attached to the vehicle by a quick release mechanism such as that of items 814, 815, 816, 817 and 818 of Figure 18G.

The main ram 991 of Figure 20B is actuated by hydraulic fluid which flows via pipes 990, 995 and valve 999, to and from the hydraulic pump 996. The hydraulic pump 996 is turned via shaft 997 by

electric motor 998. Note that typically both the hydraulic pump 996 and electric motor 998 are bi directional, such that the hydraulic pump 996 can pump hydraulic fluid out via pipe 995 (with valve 999 open) and in via pipe 990, or vice versa. Hence with valve 999 open, the electric motor 998 under the control of the vector control computer 1001, can cause the hydraulic pump 996 to actuate the main ram 991 as required, by the commands being feed to vector control computer 1001 from the master motion control (MMC) computer (not shown) in the hull of the vehicle. Once motor 998 and motor 996 are stationary, valve 999 may be closed such as to prevent any leakage via pump 996 from pipe 990 to 995 or vice versa.

An enclosed pressure reservoir 992 and 993 feeds via pipe 994 and valve 1000 and pipe 1002 to one side of main ram 991, typically it being the side (pipe 1002) under greatest pressure when the vehicle is operating normally. Within the pressure reservoir 992 is air (or other gas) and hydraulic fluid 993. Hence when valve 1000 is open (under the control of VCC 1001) then the air (or gas) 992 within the enclosed reservoir acts to provide elasticity to the suspension, due to the compressibility of gas. Additionally by controlling the closure of the typically proportional valve 1000 from the VCC 1001, the elasticity, stiffness and damping, etc of the suspension can be controlled. Also shown is an "open" reservoir 971 which may feed hydraulic fluid in or out of the pressure reservoir by bi-directional pump 972 and valve 949, and pipe 948 under the control of VCC 1001. This can be done to compensate for fluid loss from the hydraulic system or to alter the elasticity etc of the suspension, as the volume of gas 992 within the pressure enclosure is changed, due to the exit, or entry of hydraulic fluid via pipe 948.

Also shown in Figure 20B is the hydraulic system for the attitude ram 975 which all again operate under the control of the VCC 1001, in a manner similar to that of the main ram 991.

Typically main ram 991 may contain a sensor (not shown) which indicates the lineal position of the inner of main ram 991. This sensor is ideally located within the ram and its output is shown as wires 1003 which also pass to VCC 1001. Similarly attitude ram 975 may have a sensor (not shown) lineal position status passing via wires 1004 to VCC 1001.

Typically VCC 1001 will contain control algorithms and or other software means and methods such as look up tables to control the degree of actuation of the attitude ram 975, as dictated by the lineal position of main ram 991.

Additionally VCC 1001 may also use commands received form the MMC computer (not shown) in the hull to control the attitude of the wheel 950 and its turntable 951, etc as shown in figure 20A.

Reference to illustrations 20C to 20G illustrate the manner in which the position of the arms 1033, 1013, 1018 and 1027 can be changed on the vehicle by the use of the tractive power of the wheels 1031, 1015, 1016, 1029.

Figure 20C shows the arms in a typical position for travel.

Figure 20D shows the wheel 1031 being turned to a position such that its major axis is parallel with arm 1033. When 1031 was turned to this position by its turntable 1032. Wheel 1031 is now

rotated such that the tractive generated causes the arm 1033 to move to the position 1033 in Figure 20E. In Figure 20F we see the arm still moving until it reaches the position shown in Figure 20G, where it is locked by the mechanism 966 and 964 of Figure 20A.

Similarly all the other arms 1013, 1018 and 1027 will typically move in unison with arm 1033. This along with typically all wheel and other motion happens as specified by the master motion control (MMC) computer (not shown) which is typically located in the hull of the vehicle 1007. Where space is limited, one side may move at a time or otherwise, again as specified by the MMC computer.

In one form (not shown) the enclosures 965 of figure 20A may contain a actuator such as to force vertical shaft 959 to rotate about its vertical axis. This may be of benefit for example if the vehicle was stuck in a swamp, the arms of the vehicle could be moved with an action similar to that of the oars of a row boat, such as to lift and drag it over the surface, in a sequence of steps. Similarly this semi walking mode could be of benefit in climbing walls or other obstacles.

Figure 21B illustrates another application of a VWM being used on a grass etc cutting vehicle part of the chassis 1050 and 1051 is shown which connector to the enclosure 1053, 1055 and 1054 which is all typically rigidly attached to the vehicles chassis.

A VWM is mounted axially within this enclosure consisting of wheel 1060, motor enclosure 1061, strut 1062, axial section 1063 which rotates such as to steer wheel 1060, in bearings 1064 and 1065. At the top of the axial section is shown a steering motor 1070 which drives small dia gear 1071 such as to turn larger gear 1072 which is rigidly attached to the axial section 1063 such as to steer wheel 1060.

Also shown is a height motor 1080, which via belt 1082 and pulleys 1081, 1083 rotates lead screw 1086 within bearings 1084, and such as to cause the lead screw 1086 to move axially within nut 1087 such as to raise or lower the enclosure 1053, and the chassis, etc including cutter blades 1090 and 1091 above the ground.

Cutter drum 1092 rotates on bearings 1093 as forced by belt 1094, which is driven by an engine or motor (not shown). Rollers 1095, 1096 (and some not shown) run on the belt 1094. The rollers 1095, 1096, etc are rigidly supported by brackets 1097 and 1098, etc which attach to the enclosure 1053.

Figure 21A shows another possible implementation where motor 1100 acts to steer the wheel 1060 of Figure 21B when solenoid 1101 is de-energised such that teeth on arm 1102 engage gear 1103. Similarly when solenoid 1101 is energised it pulls arm 1102 such as to disengage from gear 1103, such that motor 1100 will now drive leadscrew 1004 relative to axial section 1006 (and its nut) such as to raise and lower it.

Figure 22A shows a grass mowing vehicle using one of the "wheel in a cutter" (WIC) mechanisms 1121 as illustrated in Figures 21A and 21B. This vehicle may have three wheels, one being inside the cutter, the other two are VWMs 1122 and 1123.

Also shown is the motor or engine 1124 which is rigidly attached to the chassis 1125.

The motor 1124 is shown driving the WIC 1121 via belt 1126 such as to rotate cutter drum 1127 (obscured). Typically also attached to engine 1124 is an alternator (not shown) to supply electricity for the VWM's.

Consider the three VWM's of figure 22A in a straight ahead position such that the vehicle travels in direction 1130. This is a classical way of driving a grass cutter with the cutter at the front. Similarly it can travel in the opposite direction to 1130.

A more interesting feature is when the three VWM's 1122, 1123 and that inside the WIC can be turned through 90degrees such that now the vehicle can travel in direction 1131 such as to cut under a row of fruit trees 1135, 1136, 1137, etc, with the operator at location 1129 on the vehicle, clear of branches, etc while the WIC reaches under the trees.

Figure 22B illustrates another example of a grass cutting vehicle, this time consisting of three WIC 1141, 1142 and 1143, which are attached to chassis 1144. The engine 1145 now typically driving three pulleys and belts, i.e. one to each WIC.

Figures 22A and 22B serve to show further the flexibility and control possible with the VWM's, operating under the control of a master motion control (MMC) computer.

Figure 23A illustrates a section through a polyphase axial flux wheel motor assembly which may for part of a VWM.

Figure 23B is an exploded view of the wheel motor. Rim 151 to which the tyre is fitted is attached by nuts 150 to the centre 152. Rotor 158 of the polyphase axial flux motor is attached to stub 154, the axle 157 (which is rigidly attached to the stub 154) runs in bearings 155 and 156 which mount inside enclosure 162. Also attached to enclosure 162 is a backing disk 160 and stator 159 (typically wound with copper wire, etc). Hence when polyphase currents flow through the windings on stator 159 they set up a rotating field such as to exert torque on rotor 158 and hence on rim 151 and the tyre such as to cause it to rotate.

Electronics enclosure 163 contains the polyphase inverters and microprocessor controllers etc. The calipers 164 attach rigidly to the centre 168 of the enclosure 162. Rotor 165 is rigidly attached to axle 157 such as to allow this disk brake assembly to slow, or prevent rotation of axle 157 and hence rim 151 and its tyre.

A simple strut 161 and ball joint 167 suspension is included in this illustration.

It should be appreciated that various changes and modifications may be made without departing from the spirit and scope of the claims

CLAIMS:

1. A method for controlling a vehicle of the type having a plurality of ground wheels which are individually steerable and driven such that each said wheel is tangential to a circle the centre of which is common for all said wheels.

2. The method of claim 1, wherein the RPM of the wheels is controlled as follows:

$$RPM_{\pm\Phi dn} = \frac{FR \times K_{RPM} \times (Am - FBRKm) \times Rw_{\pm\Phi dn}}{Rr}$$

Where:

$RPM_{\pm\Phi dn}$	=	The RPM command to wheel n, when in cruise mode $\pm\Phi dn$ and using vector datum point d.
Rr	=	Rc if Rc > = Ravd
Rr	=	Rav if Ravd >= Rc
Rc	=	Ssw x Kr cotan Kσ σsw
where Rc	=	The radius of the circle.
FR	=	1 when the vehicle is travelling forward
	=	- 1 when the vehicle is travelling in reverse
K_{RPM}	=	The vehicles RPM constant.
	=	The RPM of the vehicles wheels when it is travelling in a straight line (i.e., Rc = infinity) at top speed (i.e., Acc = 1).
K_{RPM}	=	$\frac{1\,000\ Vmax}{120\pi\ Rewr} = \frac{2.653\ Vmax}{Rewr}$
Vmax	=	Vehicles maximum speed in km/hr.
Rewr	=	The effective wheel radius in meters.
Am	=	Am if Am >= K_{idle}
Am	=	K_{idle} if K_{idle} > Am
K_{idle}	=	The idle constant, note its range of values includes zero
Am	=	The Accelerators Modified Primary Signal (MPS) from the accelerators displacement sensor, after passing through its Primary Modification Module (PMM).

Note: that when the signal from the

accelerators sensor does not pass via a Primary Modification Module (PMM)

then:

Am = Acc = The position of the accelerator
Note: Acc = 0, when at its rest position
Acc = 1, when at its maximum displacement

$FBRK_m$ = The Modified Primary Signal (MPS) from the force sensor on the brake pedal, after passing through its Primary Modification Module (PMM).

Note: that when the signal from the brakes sensor does not pass via a Primary Modification Module (PMM) then:

$FBRK_m$ = FBRK = The normalised force on the brake pedal.
i.e. FBRK = 0 if there is no force being exerted on the brake.
and = 1 if there is some "maximum" force being exerted on the brake.

Ravd is typically a constant, which acts to control the wheels RPM as Rc approaches zero, ie., spin on a spot mode (SOS).

A preferred value of Ravd is the average distance of the wheels from the vector datum point of the vehicle.

ie.,

$$Ravd = \frac{Rd_1 + Rd_2 + \quad + \quad Rdn + \quad + \quad Rd_N}{N}$$

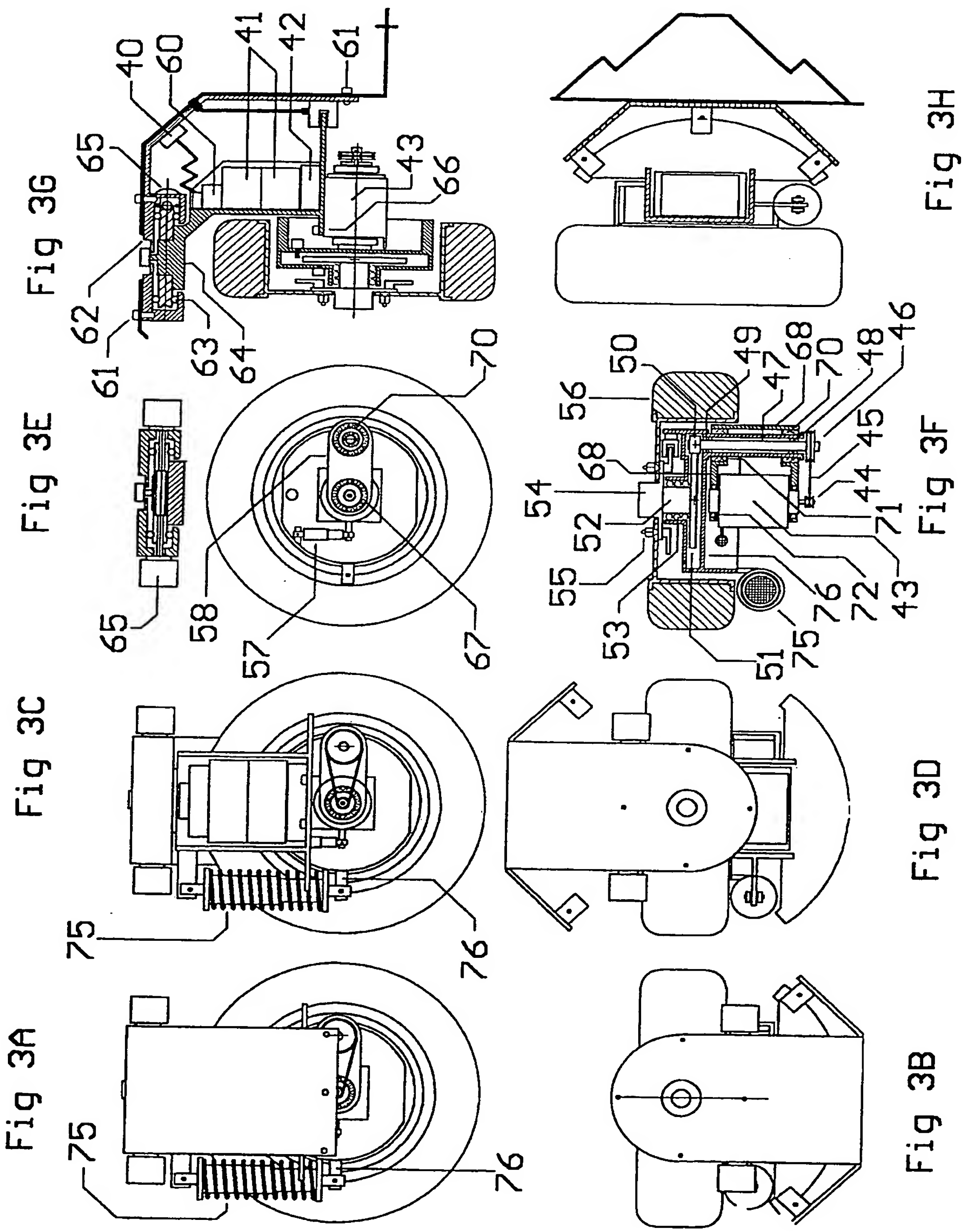
where

$$Rdn = \sqrt{X\pm^2\Phi dn + Y\pm^2\Phi dn}$$

Where N = The number of wheels on the vehicle.

Where FR = The state of the Forward / Reverse Control
Note: FR = 1 in the forward position
FR = -1 in the reverse position.

Rc = the distance of the centre of the circle



SUBSTITUTE SHEET (RULE 26)

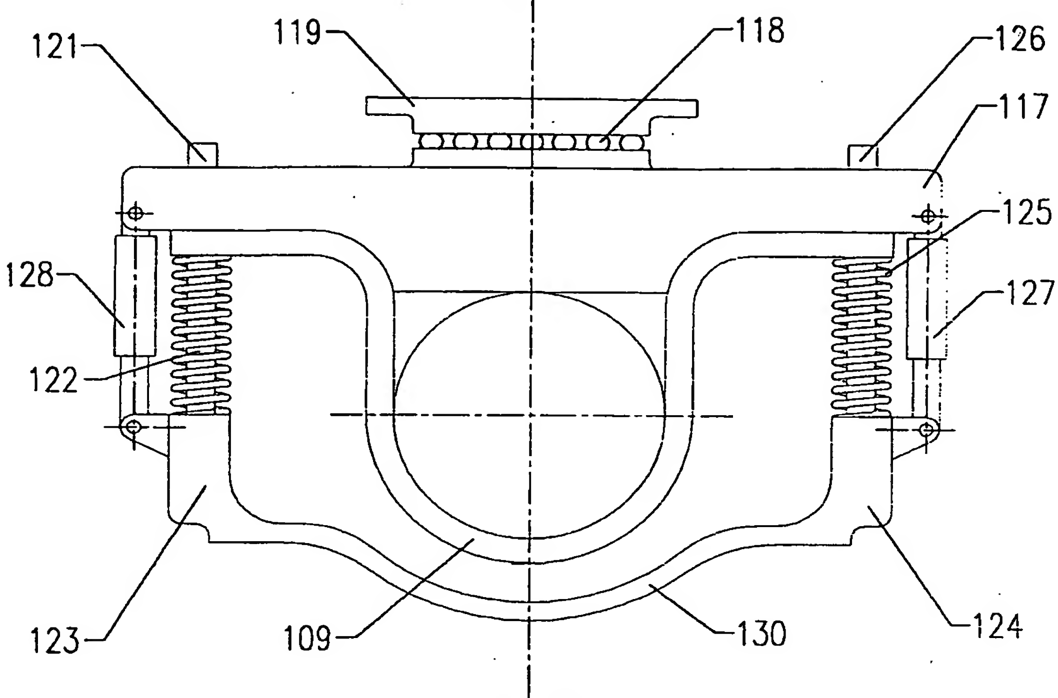

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Fig 4A

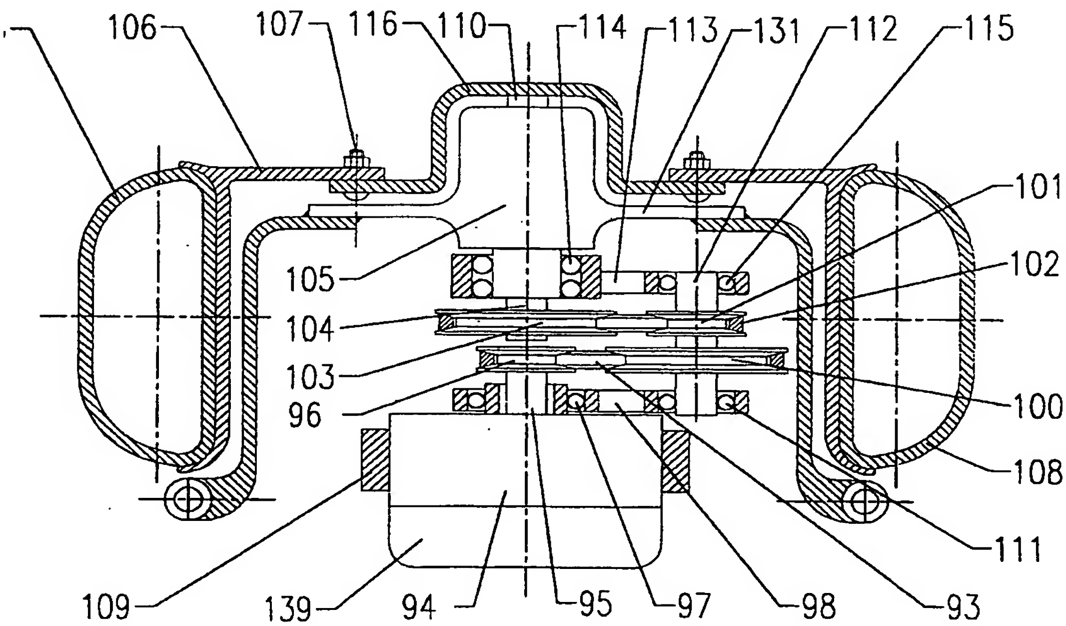
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Fig 4B

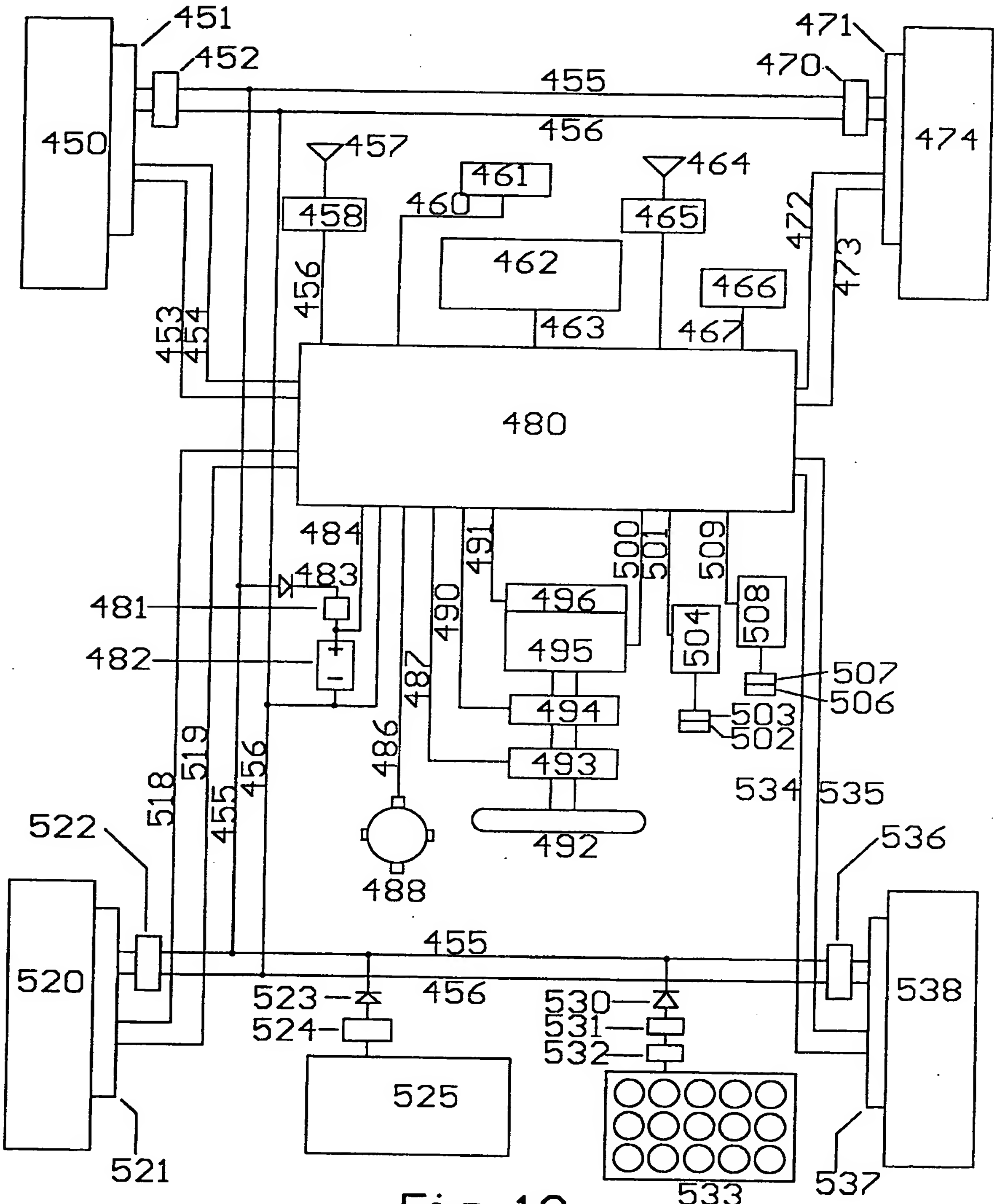
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Fig 10

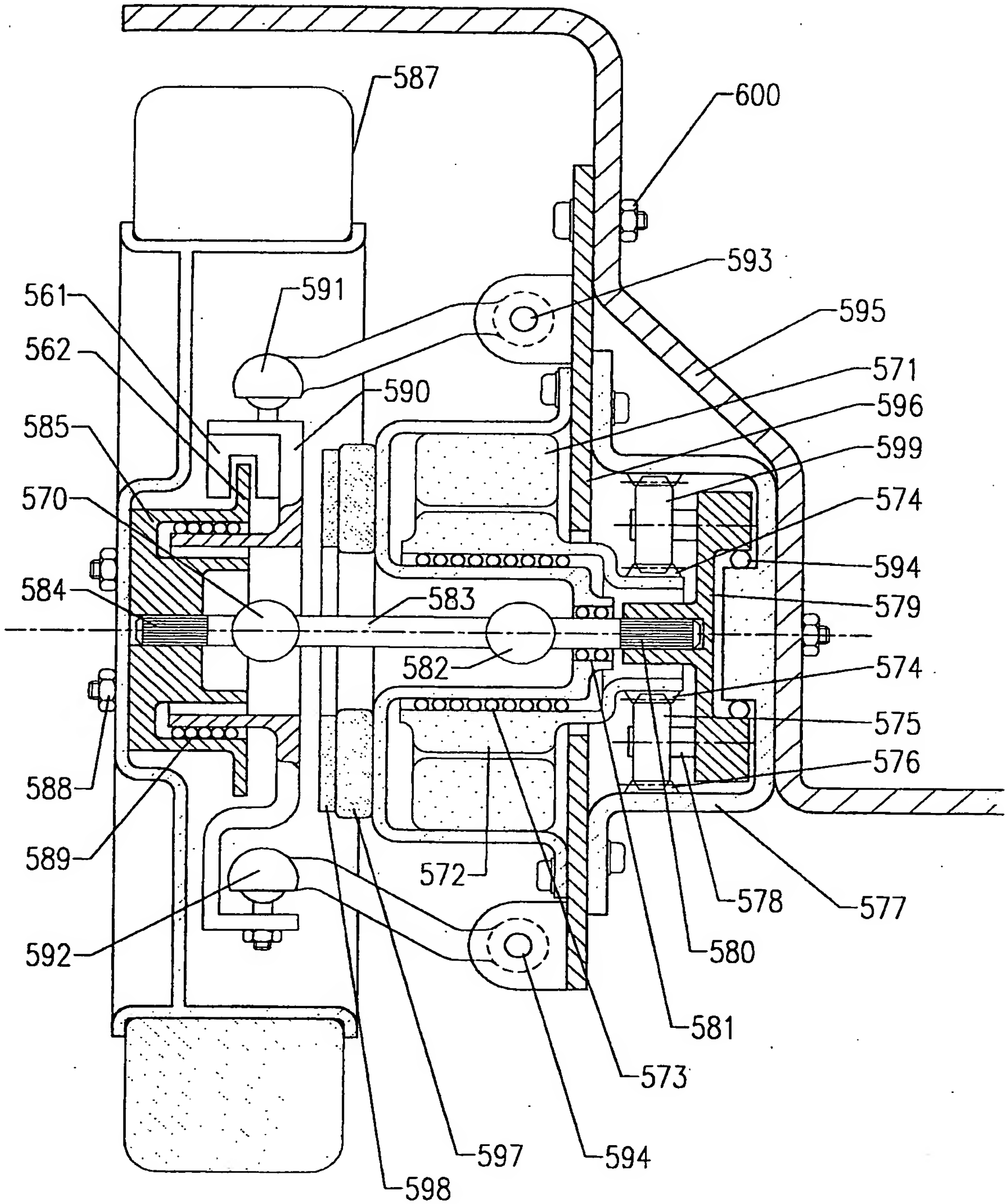
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Fig 11

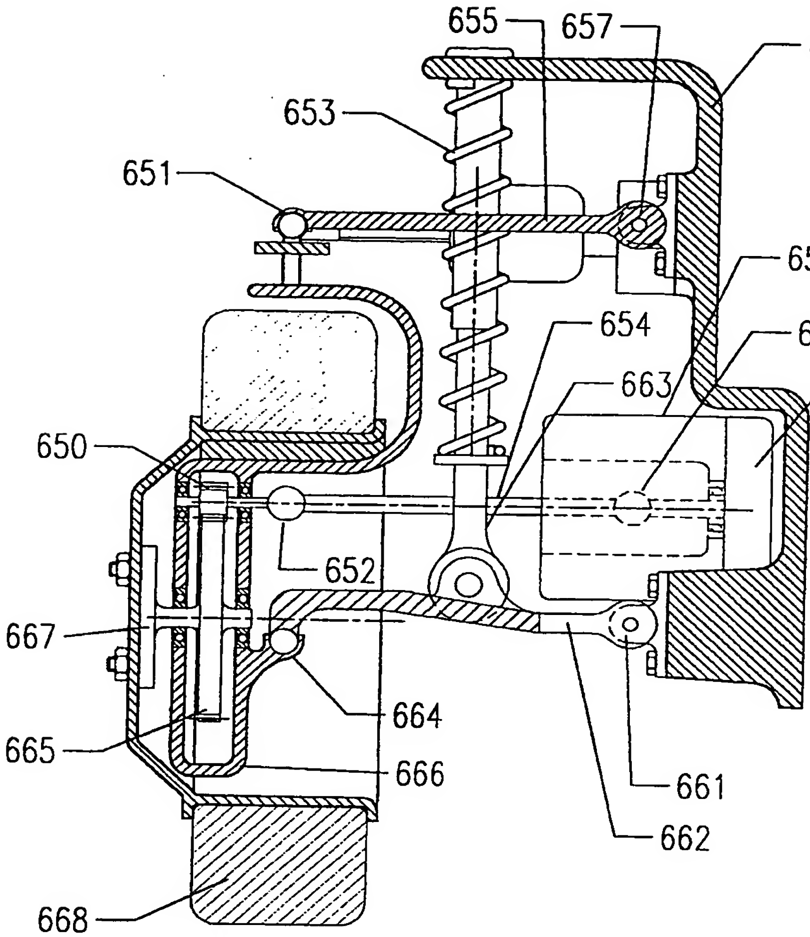

Fig 14A

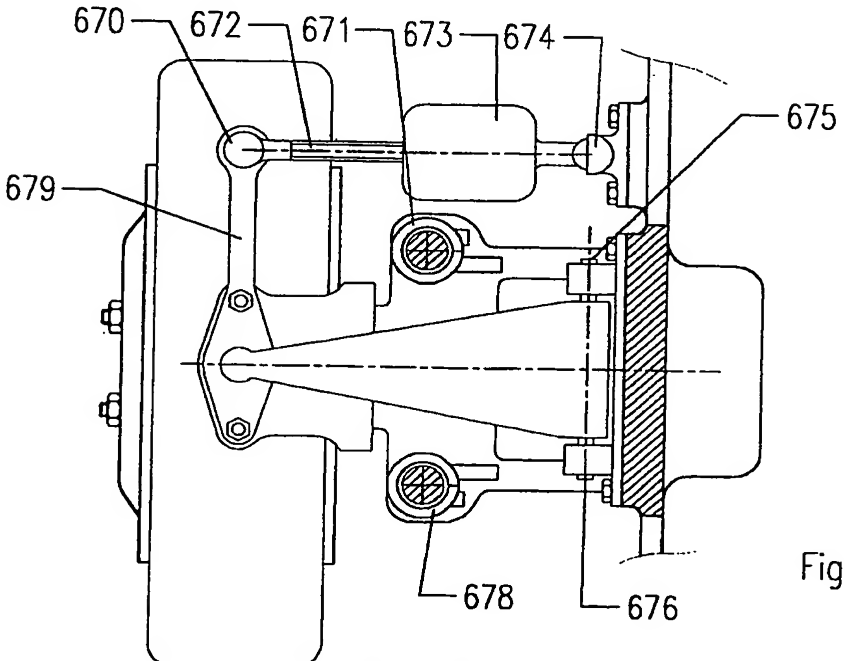

Fig 14B

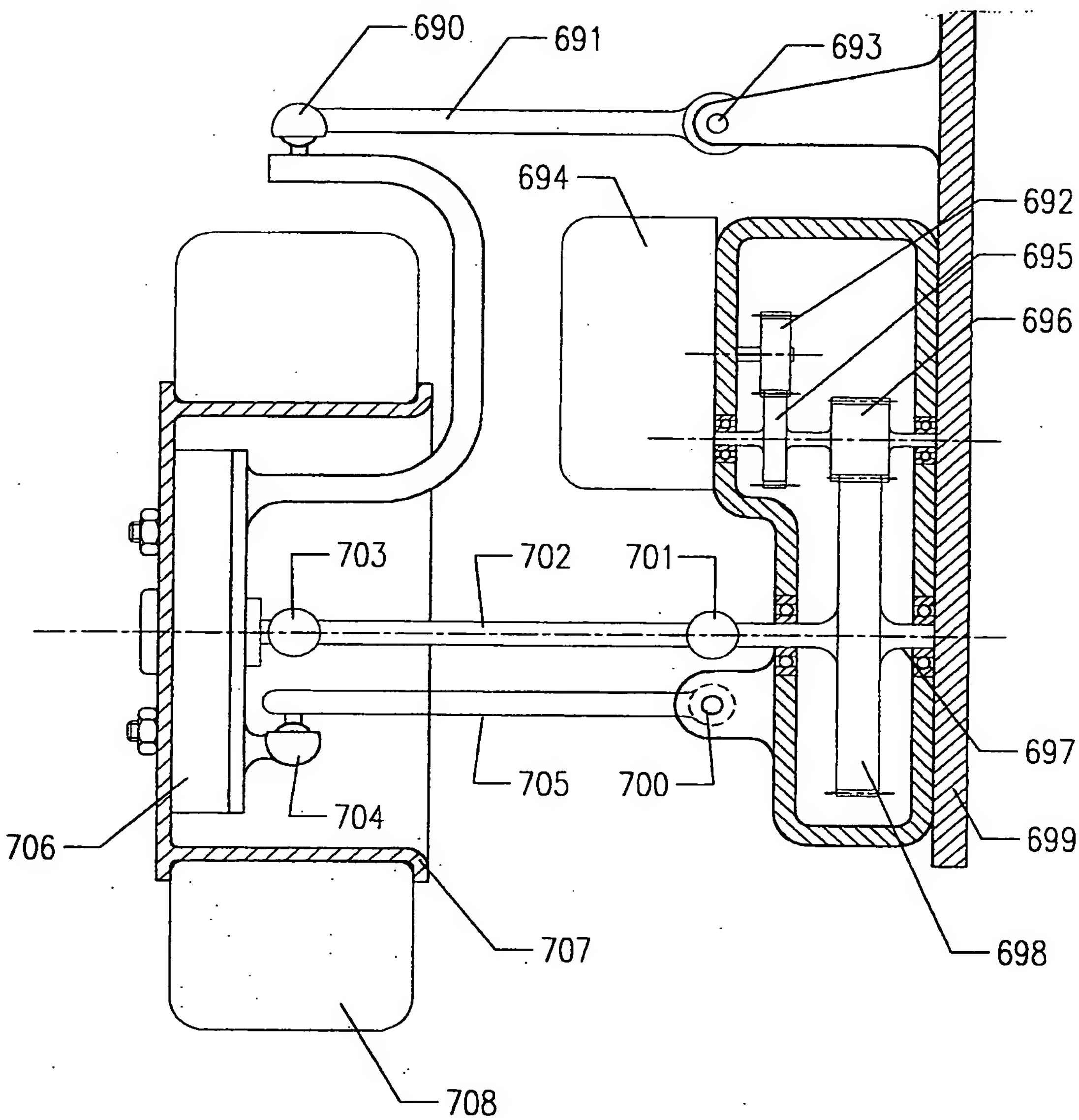
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Figure 15

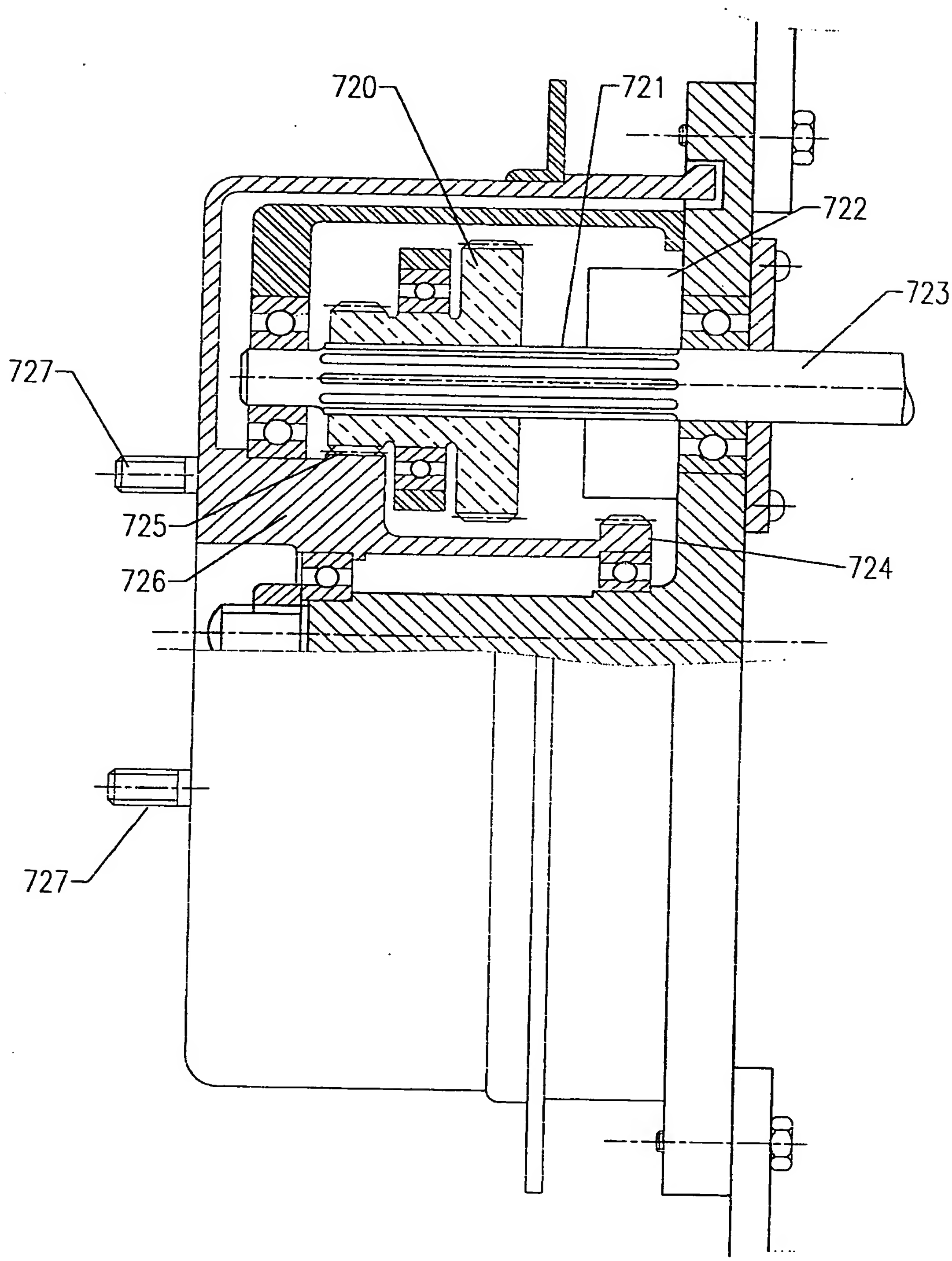

Fig 16

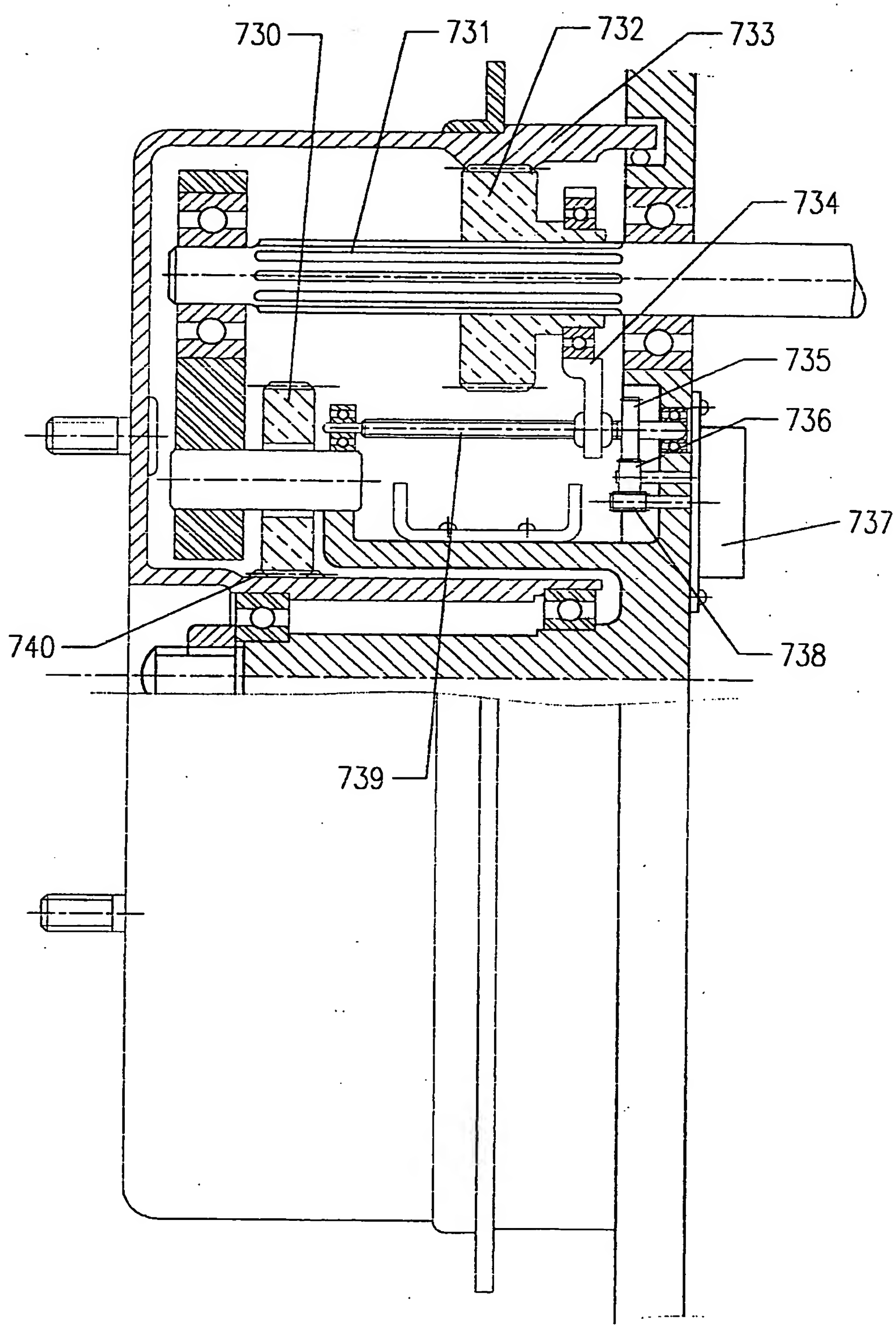

Fig 17

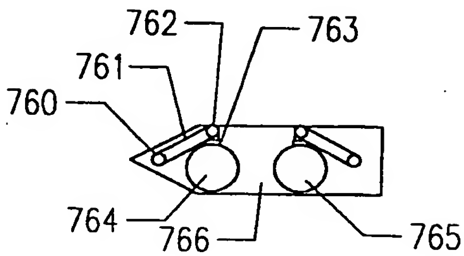

Fig 18A

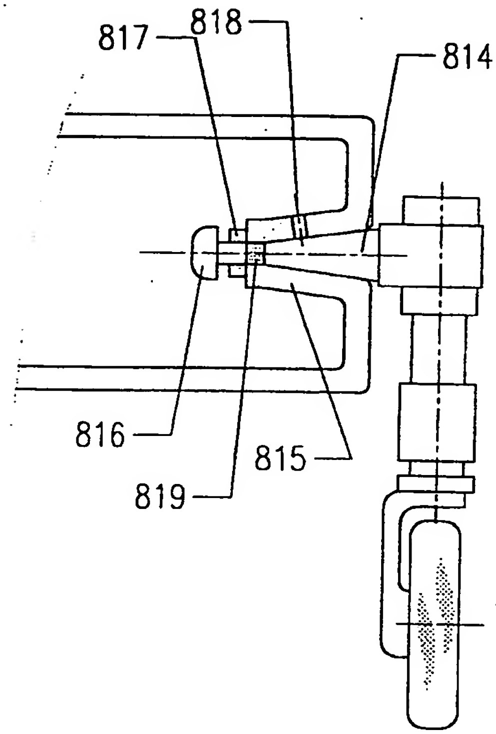

Fig 18G

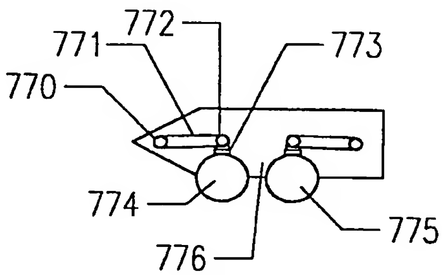

Fig 18B

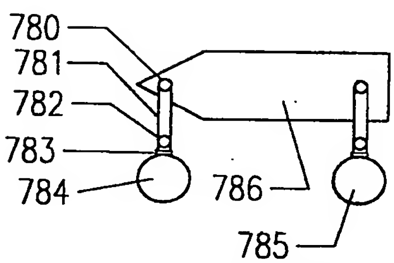

Fig 18C

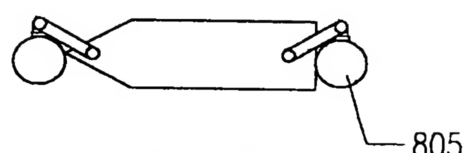

Fig 18F

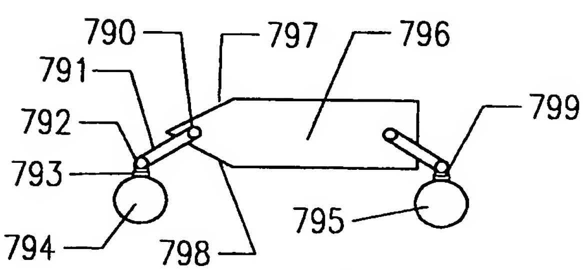

Fig 18D

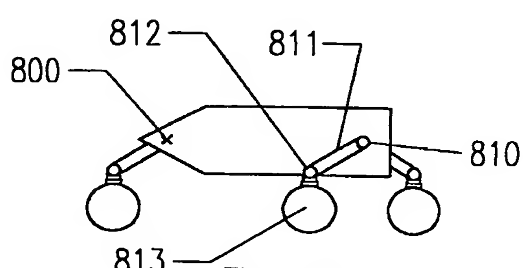

Fig 18E

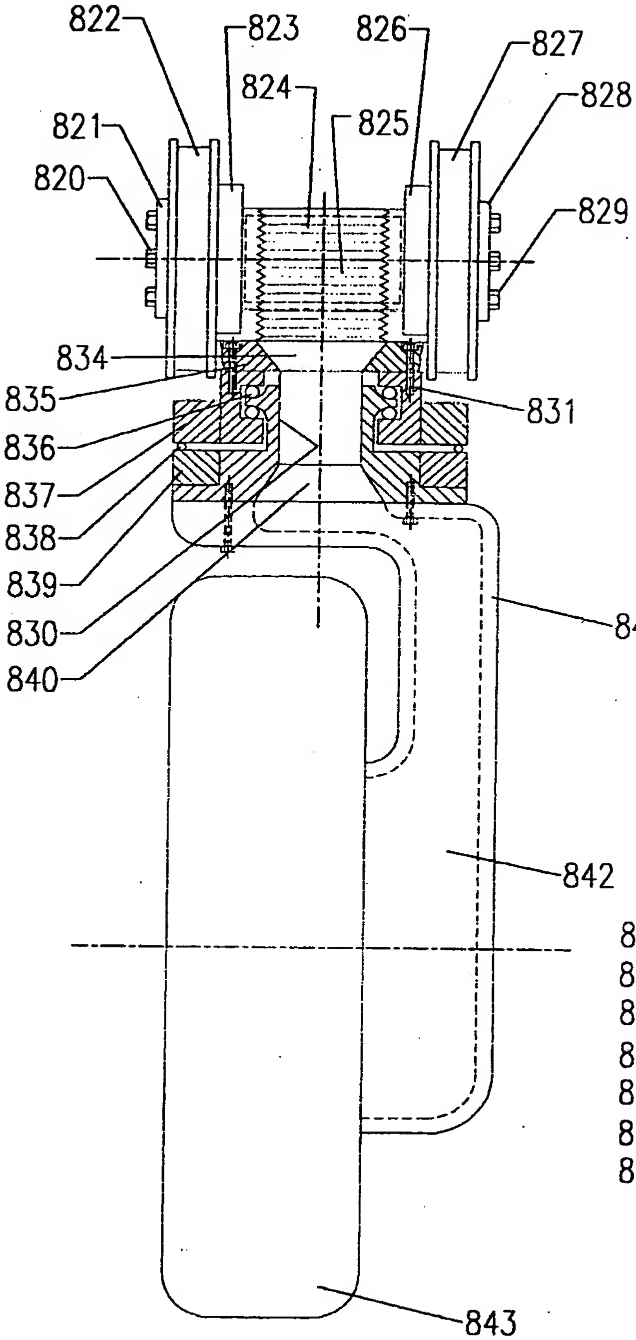

Fig 19A

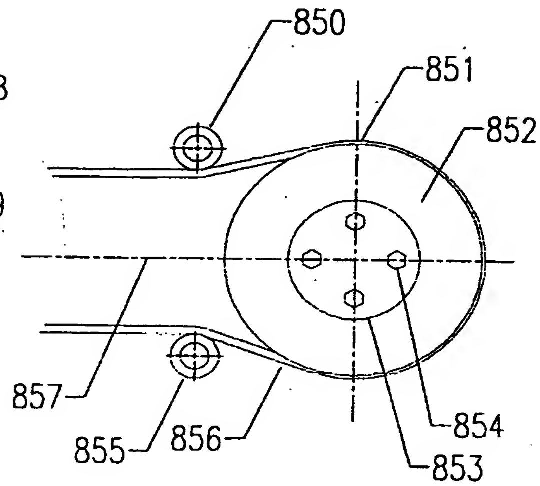

Fig 19B

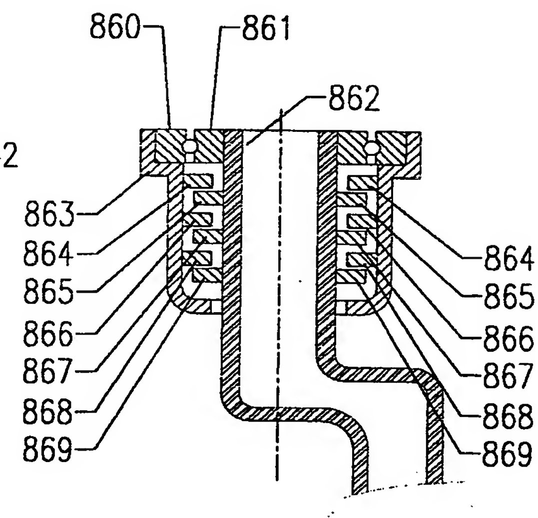

Fig 19C

SUBSTITUTE SHEET (RULE 26)

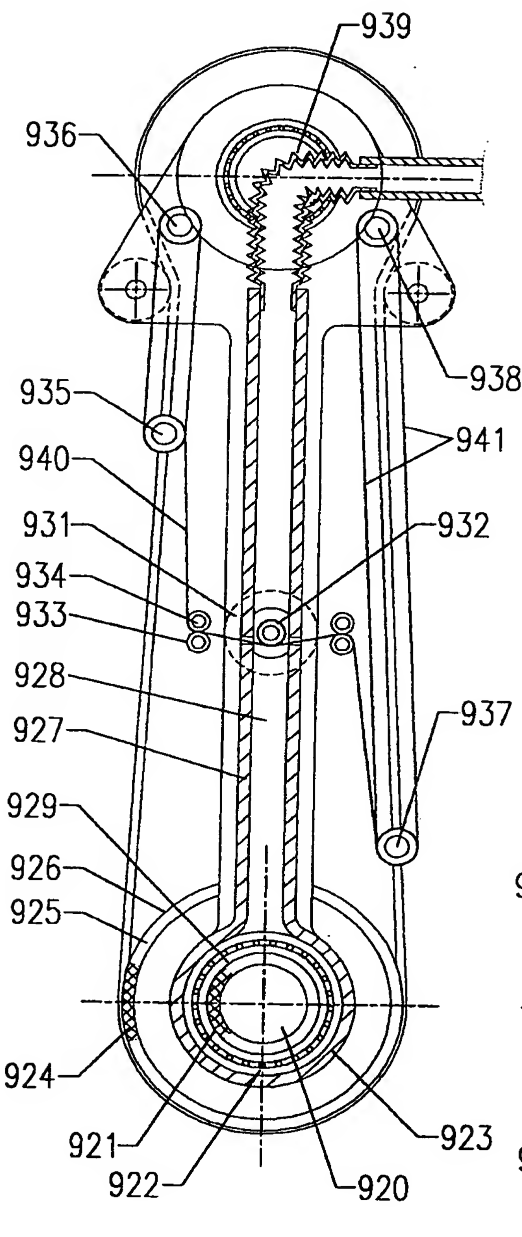

Figure 19E

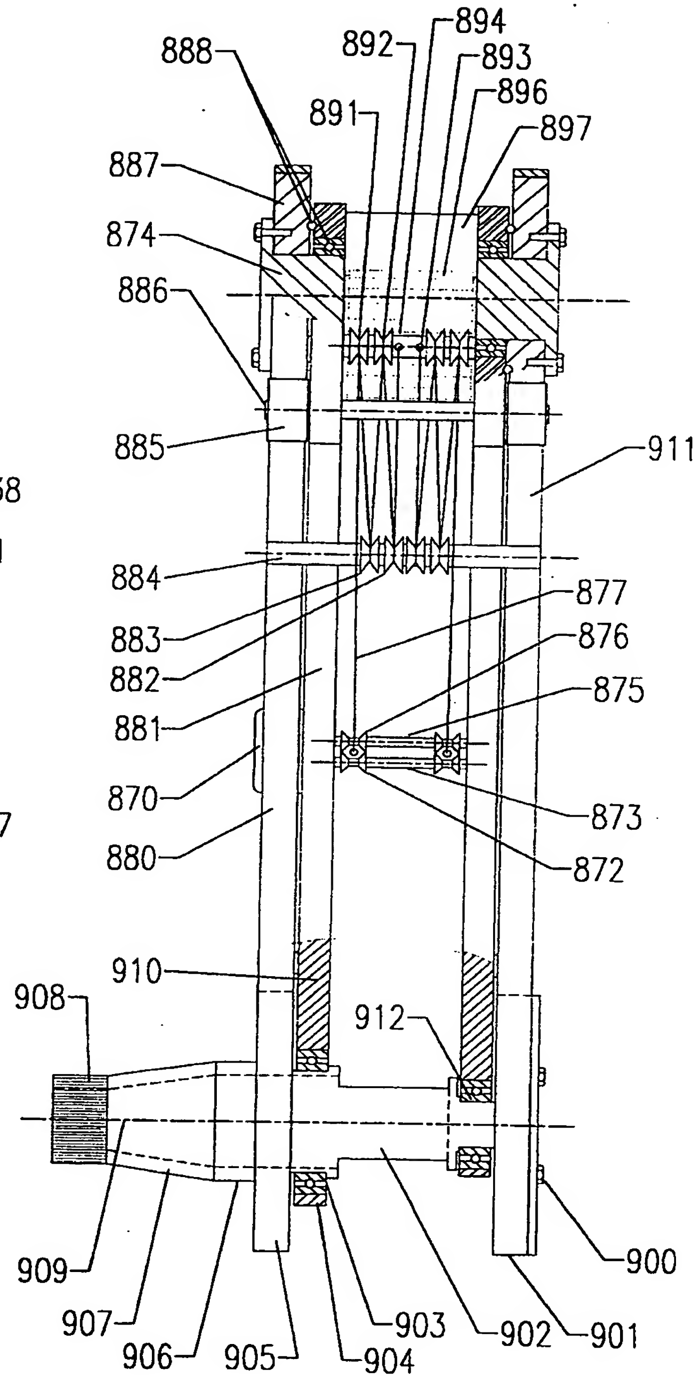

Fig 19D

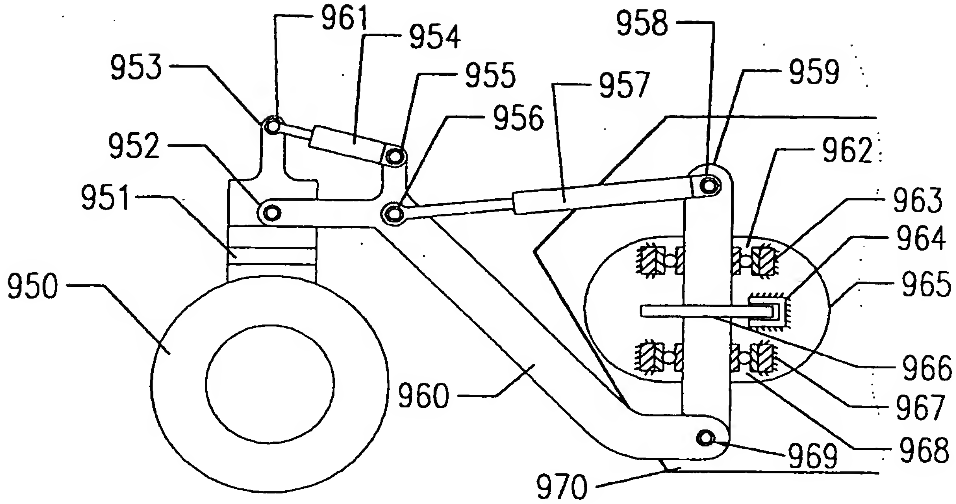

Fig 20A

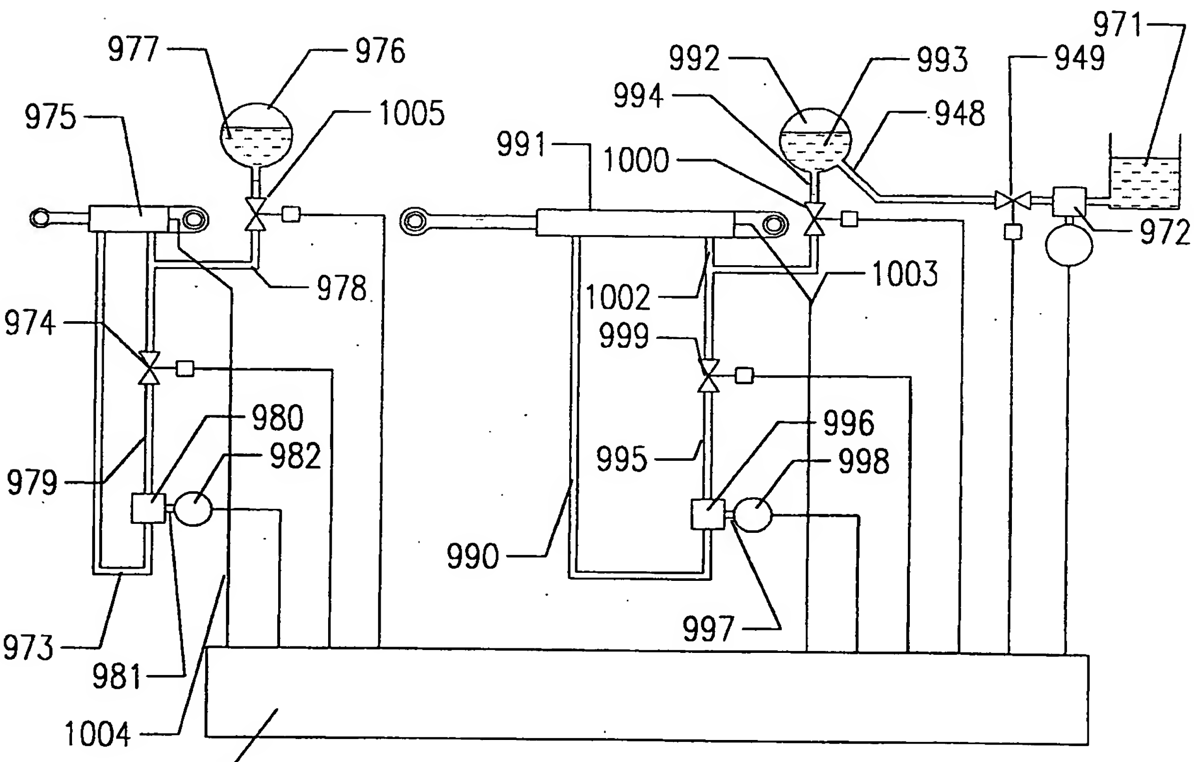

Fig 20B

INTERNATIONAL SEARCH REPORT

International application No.
PCT/AU 99/01062

A. CLASSIFICATION OF SUBJECT MATTER

Int Cl^{7}: B62D 7/15; B60K 17/30, 17/348, 17/356; B60L 15/32, 15/38

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC B62D, B60K, B60L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
AU: IPC as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
WPAT

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 4237994 A (McCOLL) 9 December 1980 Whole document	1,3,5-7
X	US 4315555 A (SCHRITT) 16 February 1988 Whole document	1,3,5-7
X	US 5014802 A (KNOLL et al.) 14 May 1991 Whole document	1,3,5-7

[X] Further documents are listed in the continuation of Box C

[X] See patent family annex

* Special categories of cited documents:

"A" Document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
22 March 2000	24 March 2000

Name and mailing address of the ISA/AU	Authorized officer
AUSTRALIAN PATENT OFFICE PO BOX 200 WODEN ACT 2606 AUSTRALIA E-mail address: pct@ipaustralia.gov.au Facsimile No.: (02) 6285 3929	ZBIGNIEW BIELAWSKI Telephone No.: (02) 6283 2218

INTERNATIONAL SEARCH REPORT

International application No.
PCT/AU 99/01062

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 98/19875 A1 (GRANT) 14 May 1998 page 4, lines 27-30; page 6, line 26-page 7, line 18	1,3,5-7
X	DE 1780534 A (BOFORS AB) 23 June 1977 Whole document	1,3,5-7

INTERNATIONAL SEARCH REPORT

International Application No.
PCT/AU 99/01062

Box 1 **Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)**

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
   because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
   because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
   because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a)

Box II **Observations where unity of invention is lacking (Continuation of item 3 of first sheet)**

This International Searching Authority found multiple inventions in this international application, as follows:

See an extra sheet.

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims
2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:
4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:
   1-7

Remark on Protest ☐ The additional search fees were accompanied by the applicant's protest.
☐ No protest accompanied the payment of additional search fees.

Box II (continued)

The international application does not comply with the requirements of unity of invention because it does not relate to one invention or to a group of inventions so linked as to form a single general inventive concept. In coming to this conclusion, the International Searching Authority has found that there are different inventions as follows:

1 Claim 1 is directed to a method for controlling a vehicle such that each of its ground wheels is tangential to a circle, the centre of which is common for all said wheels. It is considered that said method comprises a first "special technical feature".

2 Claim 8 is directed to a method of claim 1 wherein the vehicle is further characterised by infra red signature-reducing arrangement. It is considered that said infra red signature-reducing arrangement comprises a second "special technical feature".

3 Claim 9 is directed to a method of claim 1 wherein a battery pack is located with respect to the vehicle such that it can be released and, at least temporarily, discarded by release mechanism operated from within the vehicle. It is considered that said battery pack and its release mechanism arrangement comprises a third "special technical feature".

These groups are not so linked as to form a single general inventive concept, that is, they do not have any common inventive features, which define a contribution over the prior art. The common concept linking together these groups of claims is the method of claim 1. However, this concept is not novel in the light of WO 98/19875 (Grant) 14 May 1998. Consequently, the common concept does not constitute "a special technical feature" within the meaning of PCT rule 13.2, second sentence, since it makes no contribution over the prior art. Since there exists no other common feature, which can be considered as a special technical feature within the meaning of PCT rule 13.2, second sentence, no technical relationship within the meaning of PCT rule 13 between the different inventions can be seen. Consequently, it appears that a posteriori, the claims do not satisfy the requirement of unity of invention. Therefore, these claims lack unity a posteriori.

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/AU 99/01062

This Annex lists the known "A" publication level patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent Document Cited in Search Report		Patent Family Member					
US	4237994	US	4153265	US	4207956	US	4223904
		CA	1056873	CA	1084550	FI	761598
		JP	51147814	NO	761895	SE	7606345
US	4315555	NONE					
US	5014802	NONE					
WO	98/19875	AU	47670/97	NZ	335693		
DE	1780534	NONE					

END OF ANNEX